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CHEMICAL ARITHMETIC AND CALCULATION OF FURNACE CHARGES

BY

REGIS CHAUVENET

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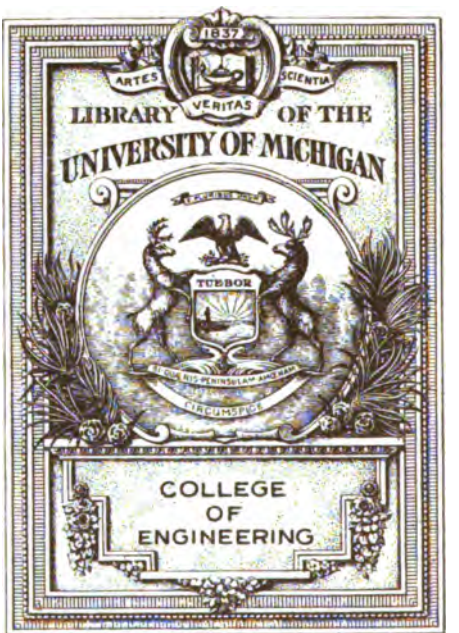

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CHEMICAL ARITHMETIC

AND

CALCULATION

OF

FURNACE CHARGES

BY

REGIS CHAUVENET, A.M., B.S., LL.D.

FELLOW COLORADO SCIENTIFIC SOCIETY. MEMBER AMERICAN INSTITUTE MINING ENGINEERS

J. B. LIPPINCOTT COMPANY

PHILADELPHIA AND LONDON

1912

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By J. B. Lippincott Company

Published March 1912

Printed by J. B. Lippincott Company
East Washington Square, Philadelphia, U. S. A.

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TO

M. A. B. AND V. M. C.

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PREFACE.

Stoichiometric calculations have formed part of chemical exercises in a number of institutions in the United States, but have rarely been reduced to a systematic course.

The present manual may serve either as a text-book, or as convenient reference for the instructor. The author has often felt the need of a work covering all the elementary subdivisions of the subject, and has included in the text all of the problems which he was accustomed to present to his classes in General Chemistry.

In Part II, in addition to the treatment of slag calculations by stoichiometric ratios, a method has been added which is believed to be of general application and may serve to greatly simplify many cases in the figuring of furnace charges.

This "Representative Equation" method has not been complicated by the assumption of "values" in the fluxing material, but no one in charge of smelting operations should be at a loss in handling this factor in the computation of products.

DENVER, COLORADO, February, 1912.

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ERRATA.

Page 149, Problem 102, for 114.016 read 102.396.

Page 154, Problem 136, for 100 liters read 1000 liters.

Page 156, Problem 155, for Light read Sound.

Page 157, Problem 165, for 1.0402 read 1.4534.

Page 158, Problem 170, for 100° C. read 10° C.

Page 159, Problem 174, for 72.8 read 44.4.

Page 165, Problem 214, read 125.611 liters. Cancel other conditions.

Page 167, Problem 228, for 3 Fe + 2 O read 2 Fe + 3 O.

Page 170, Problem 251, for 6 read 3.

ANSWERS.

Page 174, Problem 75, read 2.9867 liters.

Page 177, Problem 130, read 1.232 liters.

Page 177, Problem 132, for KOH 3390.9 read 2635.

Page 177, Problem 140, read Acid 3658.

Page 178, Problem 143, in equation for KCI read 2 KCI.

Page 179, Problem 170, for 100° read 10°.

Page 181, Problem 211, read 3494 cu. ft.

Page 182, Problem 227, read 36.8.

Page 182, Problem 228, read minus 84° C.

Page 183, Problem 243, for acid solution 3222 read acid solution 2641, for Vol. of same 2920 read 2401.

Page 183, Problem 254, read NaOH solution 5083.5.

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INTRODUCTION.

Stoichiometry is the name given to the art of chemical calculations involving the laws of combining proportions, whether by weight or volume.

It is convenient to consider in this connection certain elementary principles of Physics, such as specific gravity, and the expansion and contraction of gases under change of pressure or temperature.

The present treatise may be used as either text or reference. We here indicate what is supposed to be already familiar to the reader.

It is assumed, then: (1) that he fairly well understands the conventional or provisional meanings attached to the words "element," "compound," "atom," and "molecule." (2) That he has learned the fundamental laws of chemical combination, viz: "definite proportions," "multiple proportions," etc., and the significance of "atomic weights." (3) That he has mastered the elements of nomenclature, and can use symbols and equations intelligently.

A convenient epitome of the most important relations is found in the statement, which may be used when the meaning of "atomic weight" is fully understood:

"Elements combine in the ratios of their atomic weights, or in simple multiples of those ratios."

This is sometimes reversed, and made to serve as a definition:

"The atomic weights of the elements are the proportions in which, or in simple multiples of which, they combine among themselves."

In order to understand clearly the scope of Stoichiometry, or "Chemical Arithmetic," read carefully the following remarks.

Note first, that the definitions above given as to the atomic weights and combining ratios are quite aside from any theory concerning the nature or even the existence of atoms. In fact, while the language of the science is freely employed in the text, Stoichiometry, the "Arithmetic of Chemistry," has little to do with speculative science. Its study may incidentally enable

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the student to perceive, possibly more clearly than he has ever done before, the essential difference between *facts* which are undisputed, and the *theories*, however well grounded or widely accepted, which have been based upon them.

The discussion of a very simple equation will illustrate how theory and fact may be separated without affecting any result of chemical computation.

$$2H_2SO_4 + Na_2CO_3 = 2NaHSO_4 + H_2O + CO_2$$

We may first describe the terms of this equation in detail, saying that "two atoms of hydrogen, one of sulphur and four of oxygen, form one molecule of sulphuric acid" and so forth. Then we may proceed to state that "two molecules of sulphuric acid and one of secondary sodic carbonate produce two molecules of primary sodic sulphate, one of water and one of carbon dioxide."

But if we had no atomic theory whatever, and no system of conventional symbolism, the reaction would be just as real, and the actual weight relations exactly the same. We could say: "One hundred and ninety-six parts of sulphuric acid plus one hundred and six parts of carbonate of soda produce two hundred and forty parts of acid sulphate of soda, eighteen parts of water, and forty-four parts of carbonic acid gas." (Old nomenclature assumed.)

We might use other numbers, provided they stood in the same ratios, to express the facts.

Chemical reactions were, in fact, described much after this fashion in works printed up to 1825 and even later.

Stoichiometry then, while conveniently employing the adopted terminology, is independent of its theory.

Every strictly stoichiometric problem may be stated as a proportion. The adoption of a fixed order of statement is recommended, not as a matter of necessity, but simply to eliminate one source of possible confusion. It is well always to place the "relative" or "molecular" weights in the first member, and the actual weights (usually including the unknown), in the second.

The student cannot be too strongly impressed with the fact that the table of atomic weights shows only *ratios*, *i.e.*, the *relative* weights in which the elements combine. No amount of

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investigation of the metal tin would ever disclose the number 119. As to two elements, *e.g.*, carbon and oxygen, it would be just as correct to say that carbon dioxide contained three-elevenths of carbon and eight-elevenths of oxygen, or that it had seventy-five parts of carbon to two hundred of oxygen, as to call the relation twelve to thirty-two.

For reasons foreign to the intent of this text, the relative proportions have been reduced in modern practice to the weights as given in Table I, in which the element oxygen is conventionally assumed as 16, all the other elements assuming numbers *relative* to that one in accordance with numberless experiments, which, from the early work of Berzelius in the first part of the nineteenth century, have been carried on with ever increasing accuracy to the present day.

It is, however, not necessary, in the working of problems for exercise, to use the exact atomic weights. In the table and in the table of factors (II) and percentage composition (III) the exact numbers are used, either directly or as data for computation. But unless otherwise stated, we use in the problems the *nearest whole number* except in the case of chlorine, whose atomic weight is made 35.5 in the computations in which all the other elements are taken to the nearest whole number.

The equality sign is used between the members of a proportion, instead of the old-fashioned "four dots." The student should realize that a ratio is a pure number, and a proportion an expression of the *equality between two pure numbers.*

In the treatment of gas volumes the "two volume" convention is retained for the molecule. It has proved better as a class-room method in the author's experience than the more recent "one volume." It is a matter of small importance as compared with the necessity of recognizing relative volumes upon inspection of the equations, and all other detail following from "Avogadro's rule." This being a matter upon which many technical men quickly become "rusty," some space is devoted to its elementary exposition, before the introduction of problems.

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PART I
CHEMICAL ARITHMETIC

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CHEMICAL ARITHMETIC.

SOME FUNDAMENTAL LAWS OF CHEMISTRY.

Conservation of Mass.—Matter is not destroyed by any chemical action; its mass remains constant, whatever its change of physical condition.

Definite Proportions.—In every chemical compound the constituents occur in definite unalterable proportions by weight.

Multiple Proportions.—When two elements unite in several proportions, and we regard fixed weights of one element, the quantities of the second element will bear a simple ratio to each other.

Avogadro's Rule.—The number of molecules in a unit volume of all gases is the same, temperature and pressure being equalized.

Gay-Lussac's Law.—When gases unite, the volumes both of the constituent parts and the product bear to each other some simple ratio.

Boyle's Law.—The volume of a mass of gas varies inversely as the pressure on it.

Charles' Law.*—The volume of a gas varies directly as the absolute temperature to which it is exposed.

Dulong and Petit's Law.—The product of the atomic weight of an element by its specific heat is a constant, substantially the same for all the elements.

*Gay-Lussac's name is retained for the law of gas unition. Charles' name is used more for distinction than as a matter of history; probably Gay-Lussac made the first definite enunciation of the law.

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DEFINITIONS.

An atom is the least mass of an element that can take part in a chemical reaction.*

A molecule is a particle of matter representing the limit of divisibility so far as similarity goes. ("Physical identity" limit.*) (A molecule may be either simple or compound. There are probably monatomic molecules. It is not necessary to connect the idea of "indivisibility" with the chemical atom.)

Atomic Weights.—The proportions in which or in simple multiples of which the elements unite among themselves.*

Molecular Weight.—Sum of all the atomic weights contained in a molecule.*

Specific heat of a substance is ratio of the quantity of heat required to raise a given weight of it one degree, to quantity required to raise an equal weight of water one degree. (Practically, the specific heat of water being assumed as unity, the specific heats of all other elements are represented by numbers bearing the proper ratios to unity as deduced from experimental data.)

Atomic heat of an element is the product of its atomic weight by its specific heat. Under the supposition naturally arising from Dulong and Petit's law, all atoms should have the same capacity for heat.

Specific Gravity.—Weight of a substance as compared with the weight of a standard substance of equal volume. (Illustrations of this property will be found in detail under the proper heading.)

Density.—This term is reserved for the specific gravity of gases, with $O_2 = 32$ as basis of comparison. This brings molecular weight and density of a gas to the same figures, instead of the 2 : 1 ratio.

Atomic Volume.—Quotient of atomic weight divided by specific gravity. Since (see "Specific Gravity")

$$V = \frac{W}{G}$$

*These are definitions sufficient for "stoichiometric" calculations.

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then on the assumption that the atomic weights are the *relative* weights of atoms, their *relative volumes* will be indicated by

$$\text{at. vol.} = \frac{\text{at. wt.}}{\text{sp. gr.}}$$

If atomic weight be taken *in grams* then atomic volume will indicate volume in c.c. *Example.*—Lithium, at. wt. = 7.00, sp. gr. = 0.59, at. vol. = 11.86. Then 7.00 grams will occupy 11.86 c.c. in volume.

Absolute Temperature.—Temperature measured on a thermometer whose "zero" is fixed at *minus* 273° Centigrade. The degrees themselves are of the same value as degrees Centigrade, *i.e.*, the interval between degrees indicates the same difference in temperature. (See section on "Thermometers," and "Charles' Law.")

Pressure.—Pressure in chemical and physical experiments is almost invariably measured by the barometer. In English measures the barometric column is read in inches, and 30 inches is usually taken as the "normal" pressure. In barometers divided by metric linear units, the readings are in millimeters. "Normal" is taken as 760 millimeters. The two do not quite correspond, as 30 inches = 762 millimeters, absolutely, 761.99 mm.

Many laws and definitions are omitted in this summary, because we shall not extend our treatment of chemical problems into their domain.

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PRELIMINARY REMARKS.

"*The molecular weight of a compound is the sum of the atomic weights of its elements.*" This may be taken as an independent law, or, assuming the truth of the atomic theory, as a necessary sequence.

In "manganese pyro-phosphate" formula is $Mn_2P_2O_7$. Knowing atomic weights of the elements we deduce "molecular" weight of the compound, thus:

Manganese	Atomic weight of manganese = 55...	Mn_2 = 110
Phosphorus	Atomic weight of phosphorus = 31...	P_2 = 62
Oxygen	Atomic weight of oxygen = 16...	O_7 = 112
Sum, or "molecular" weight of $Mn_2P_2O_7$		= 284

In using chemical equations, always "balance" them, *i.e.*, see that atoms (symbols) of an element on one side equal those of same element on the other side.

A common blunder in calculating weight of a compound from given weight of another one is to *forget the doubling of a symbol* or some other change involved in the change of formula.

Example.—What weight of K_2O can be derived from one gram of KCl?

The student well used to the arithmetical handling of formulæ will see at once that the weight of the K_2O must be less than that of the KCl. If a novice he is liable to the blunder of stating his proportion thus:

$$KCl : K_2O = 74.5 : 94 = 1 : 1.26$$

not seeing that he has "created" an atom of potassium and half an atom (!) of oxygen. The true solution requires the equalization of the atoms at the start; for instance, call the "KCl," "2KCl," then we get the true proportion:

$$2KCl : K_2O = 149 : 94 = 1 : 0.63$$

For only one molecule of K_2O can be derived from two molecules of KCl.

Similarly, if the percentage of MgO should be required in $Mg_2P_2O_7$, we should calculate for "2MgO," not for "MgO."

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The ratio between the formulæ of "sought" and "found" is sometimes less simple than in the above examples.

Suppose that we have the weight of uranium phosphate, $(UO_2)_2P_2O_7$. It is required to find the factor by which this weight must be multiplied to obtain the corresponding weight of the oxide U_3O_8.*

Direct comparison of the molecular weights will not serve, because the formulæ show, respectively, two and three atoms of uranium. If, however, we multiply the molar weight of the phosphate by three, and that of the oxide by two, we shall have in each product six atoms of uranium, or two molecules of the oxide, U_3O_8. In other words, three molecules of the phosphate are shown to contain two molecules of the required oxide. By division under the rules to be given in the text we now readily deduce the factor 0.7865.

The careless use of symbols is an error to which many are liable. It is erroneous to write the symbol as a mere abbreviation of the name, convenient though it may often seem. *The symbol carries with it, understood, the atomic weight, and it stands for one atom.*

Some further mention of this will be found in the metallurgical part of the work. Generally the use of the symbol should be discouraged except in such connections that it expresses exact relations as denoted by its numerical value.

The reader unaccustomed to the metric system should attack it at once. If he imagines that it presents difficulties because it is not what he is used to, he is reminded that he has figured all his life in ordinary numeration and in U. S. money, which are decimal, as is the "metric" system.

Much of the mistaken notion as to the difficulties of the system may be traced to the prevalent methods of instruction concerning it, especially in the Public Schools, where it is overloaded with nomenclature, obscured by comparison with the ordinary system and tables, and, in short, made as difficult for the struggling infant as could be desired by his worst enemy. See, however, under the section devoted to this topic for details.

Every person should carry with him a "sense of magnitude" for the correction of gross errors. Of these the most common is

*Weight of U_3O_8 that can be actually obtained from the "known" or "given" weight of $(UO_2)_2P_2O_7$.

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the misplacing of the decimal point. This, however, can be only "learned," not "taught." A person who could work the proportion $3 : 6 = 0.15 : x$, and find x equal to 3, instead of 0.3, may have merely made a slip in the application of the rule, and that is excusable. However, not to see the error by "instinct" would be indeed unpardonable. The retention in the mind of the "order of magnitude" for the answer to a simple proportion is an easy habit to acquire, and may save many a bothersome error. Take the case above. The computer should perceive as he sets down his figures that the answer must be less than unity.

Under the definitions above of "atom" and "molecule," also of atomic and molecular "weights," the reader trained in chemical theory will not fail to note the defects of these provisional definitions. They are nevertheless retained, for the reason indicated in the footnote, viz: they suffice for the purposes of stoichiometric calculations.

Strictly (using the old convention of unity for the atomic weight of hydrogen) the "atomic weight" of an element is the number of times which the mass of the least portion of it that can take part in a chemical reaction is greater than the least portion of hydrogen that can take part in a chemical reaction. The "molecular weight" of any substance (elementary or compound) would then be the number of times that the mass of the smallest portion of it that can exist in the free state, is heavier than the atom of hydrogen (or "the least portion of hydrogen that can take part," etc.).

Many of the explanations in the text will strike the expert as puerile. They are meant to be. Nothing more astonishes the writer than the inability of many technical men to attack the simplest chemical problems. Graduates in chemistry, with mathematics enough to compute bridge strains, turn pale at the idea of "tackling" an elementary case of stoichiometry. "Please assume, to begin with, that I have forgotten all that, if I ever knew it," would be a fair average estimate of their attitude. Excepting, then, the already excepted "fundamenta," all else is explained where there seemed to be the slightest chance for misapprehension.

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THERMOMETERS.

Two thermometric scales are in common use, the "Centigrade" and the "Fahrenheit." The "Absolute" scale to be presently explained is convenient for the calculation of gas volume variations under heat, but has no other usual application.

Zero of the Centigrade scale is fixed at the melting point of ice. The boiling point of water (at 760 mm. pressure) fixes the 100° point.

Zero of the Fahrenheit scale is fixed at 32° (F.) below the melting point of ice. The boiling point of water is at 212°.

Thus between temperatures of melting ice and boiling water we have 100 degrees Centigrade, and 180 degrees Fahrenheit.

Since 100 degrees C. are equal to 180 degrees F., 1° C. = 1.8° F., which is usually expressed by saying that one degree C. equals nine-fifths of a degree of F., or conversely one degree F. equals five-ninths of a degree C.

To Convert Fahrenheit Degrees into Corresponding Centigrade.—"*Subtract* 32 and take five-ninths of the remainder."

Example.—What degree C. corresponds to 239° F. ? 239 − 32 = 207. Five-ninths of 207 is 115.—*Answer.*

To Convert Centigrade Degrees into Corresponding Fahrenheit.—"Take nine-fifths of the C. degrees and then *add* 32."

Example.—What degree F. corresponds to −10° C.? Nine-fifths of −10 is −18. −18 + 32 = 14.—*Answer.*

NOTE.—In *starting* from F. make the 32° correction *first*. In *ending* with it, make it *last*. This is merely mnemonic, but is sometimes useful.

Examples in Conversion of Degrees from one Thermometric Scale to Another.—(*a*) What temperature is expressed by the same number of degrees in either Fahrenheit or Centigrade scale?

Solution. $\frac{5}{9}(x - 32) = \frac{9}{5}x + 32$. *Ans.*, $x = -40$.

(*b*)	275°	F	=	135°	C.	(*i*)	0°	C.	= + 32°	F.
(*c*)	23°	F	= −	5°	C.	(*j*)	100°	C.	= + 212°	F.
(*d*)	0°	F	= −	17.78°	C.	(*k*)	− 10°	C.	= + 14°	F.
(*e*)	− 40°	F	= −	40°	C.	(*l*)	− 40°	C.	= − 40°	F.
(*f*)	− 112°	F	= −	80°	C.	(*m*)	35°	C.	= 95°	F.
(*g*)	212°	F	=	100°	C.	(*n*)	− 71°	C.	= − 95.8°	F.
(*h*)	73°	F	=	22.78°	C.	(*o*)	− 16°	C.	= + 3.2°	F.

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"Absolute Scale."—To pass from Centigrade to "absolute" add 273. To pass from "absolute" to Centigrade, subtract 273.

Zero degrees "absolute" equals *minus* 273° Centigrade.

Zero degrees "absolute" equals *minus* 459.4° Fahrenheit.

It must not be forgotten that the "degree" is the same in the Centigrade and "absolute" scales, that is to say, the size or amount of difference in temperature indicated by any number of degrees is identical.

Hence, should it become necessary to convert Fahrenheit into "absolute," or the reverse, *first convert into Centigrade*, and then proceed.

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THE METRIC SYSTEM.

We have assumed that any student in a technical school who may use this work is familiar with the metric system.

There are many, however, whose acquaintance with it is slight and to whom, because they were never rationally taught, it seems not only difficult but even "unnecessary."

For those who may now for the first time meet the system, a few observations are appended. They are intended less as expository than as hints for the best method of acquisition. Indeed, they are largely negative—"how *not* to attack the subject."

First: Do *not* bother about the relation of the metric system to the common system of weights and measures. That relation has nothing to do with any calculation. One might in fact make perfectly correct calculations in the metric or any other system without having the slightest idea of the magnitude of the concrete units figured upon.

Practise, then, with the aid of the examples given; do not ask, "What are the equivalent magnitudes expressed in every-day units?"

If it be desired to translate results in one system into the units of the other, it becomes a mere matter of reference to the tables showing the relation. That, however, is simply the application of a factor. In time, as one becomes accustomed to refer to both systems, some mental approximation will present itself without effort. But in the first acquisition, surely it is useless and confusing to stop at every step to consider what the numbers you are using may mean in another set of magnitudes.

Second: Do *not* try to memorize the tables. Especially, do *not* try to learn *all* the names of the multiples and submultiples of the various units. The names are logical enough, and any one using the system will soon find that they will come naturally to him, if he wants them. But in truth they are very largely unnecessary in practice. The reason is that, after all, the subdivisions are nothing more than tenths, hundredths and thousandths, or the multiples are ten times, a hundred or a thousand

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times. So, having the names of the *units* of length, volume or weight, the "names" of the subdivisions are of exceedingly little importance.

It is true that certain submultiples are so frequently used that it is *convenient* to acquire and use their names. But the really important thing is to know the nature of the system, and it would be perfectly easy to use it with no names for the subdivisions except the inevitable ones of tenths, etc.

Third: If the student (in school or out of it) will get it fixed in his head that he has *been using the metric system all his life*, that will be the last of any "difficulty" in the case. Now we are addressing some one who has little or no knowledge of the system in practice, and we adopt the familiar form of remark and answer. Remarks in italics, answers in Roman.

"*You understand already how to compute in the metric system.*"

"How so?"

"*Because you have never computed in any other system in pure numbers, or in United States money. Because the "method" of calculation in the metric system is absolutely and entirely the same as calculation in ordinary numbers and their decimals. Here is a problem for you*:

"*Add* 3.52 *to* 9.67."

"Why, 13.19, of course."

"*Correct. It was a problem in the metric system and you have solved it.*"

"But in what denomination? Weight, length or volume?"

"*It matters not. They all subdivide decimally. Add, subtract, multiply, divide, equate, or proportionate, they are treated just the same as pure numbers.*"

To this statement we add for the beginner the relations of length to volume, and of the latter to weight, which indeed constitute the greatest beauty as well as simplicity of the system.

We shall now give a tabular statement of the system, accompanied by a few explanatory remarks.

Tables of ordinary concrete numbers are also given, and "conversion" factors from each system to the other.

Here we again warn the learner that he is not to perplex himself with these relations. *They are figures for reference.*

Under the head of problems in gas volumes are methods of transition from the metric system to the ordinary.

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Verification of the problems under this head (metric system) will go far to render all the relations of the various tables of the system quite easy. Nothing, however, can make it half as easy as to actually do work with the linear, volumetric, and gravimetric units themselves.

METRIC SYSTEM, TABULATED

Length.—Unit, the METER (m.).

SUBDIVISIONS.	MULTIPLES.
0.1 meter = 1 decimeter (dm.).	10 meters = 1 decameter.
0.01 meter = 1 centimeter (cm.).	100 meters = 1 hectometer.
0.001 meter = 1 millimeter (mm.).	1000 meters = 1 kilometer.

The meter is properly the basis of the whole metric system. It may assist the learner to remember that it is very little over a yard in length.

In reading numbers in the system, remember that it is not usual, and certainly not necessary, to name each subdivision. In reading United States money we name only dollars and cents, *e.g.*, $315.28, three hundred and fifteen dollars and twenty-eight cents.

Suppose we are reckoning in meters. Take the number 6.139 m. We read it just as we would a number, probably "six (point), one, three, nine, meters." It is true that some unhappy children are still taught to say "six meters, one decimeter, etc." That, however, is merely a case of the illegal survival of infant torture.

Since the system is purely decimal, its divisions, as inculcated above, are treated in all respects, in calculation, like pure numbers.

Although in naming a compound quantity like the above we do not use the subdivisional names, yet the names centimeter and millimeter are familiar in the laboratory in naming lengths *less* than a meter. The name kilometer is becoming familiar in the United States. It is close to five-eighths of one mile.

Area.—The intended unit is the ARE or one hundred square meters. Being too large for laboratory use and too small for land measurement, it is not much heard of. In land measurement, 100 "ares" or one "hectare" are chiefly used. The "hectare" is about two and one-half acres.

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As all areal measurements (metric or others) go upon squares for their bases, it is evident that as the linear dimensions are multiplied by 10, the areas are multiplied by 100.

100 square millimeters (smm.)	= 1 square centimeter (scm.).
100 square centimeters	= 1 square decimeter (sdm.).
100 square decimeters	= 1 square meter (sm.).
100 square meters	= 1 ARE.
100 ares	= 1 hectare.

We have very little to do with areas in the present work.

Volume.—All volumes are considered as cubes, whose edges are the standard length measures. Unit of volume, the LITER (the cube whose edge is one-tenth of a meter*).

1000 cubic millimeters (cmm.)	= 1 cubic centimeter (c.c.).
1000 cubic centimeters	= 1 LITER (cubic decimeter, cdm.).
1000 liters	= 1 cubic meter ("Stere").

The liter happens to be very close to a quart. We shall use the common laboratory abbreviation, c.c., for cubic centimeter.

Weight.—Weights are based upon standard volumes of water at 4° Centigrade (maximum density). Unit, the GRAM. A gram is the weight of a cubic centimeter of water under above conditions. It is a convenient laboratory unit. Commercially, the KILOGRAM ("kilo") becomes the practical unit. The latter may be remembered as about two pounds avdp.

1000 milligrams = 100 centigrams = 10 decigrams = 1 GRAM.
1000 grams = 100 decagrams = 10 hectograms = 1 kilogram.
We have also, 1000 kilograms = 1 metric ton (tonne).

Considering the volumes above, we see that as the edge of a cube is multiplied by ten, its volume is multipled by 1000 ($10^3 = 1000$).

As already mentioned in foot-note under volumes, the weight of a liter of water is one kilogram.

A few problems are annexed. But nearly every problem in the book involves the application of the system.

Questions given in grams, etc., might be solved in ounces provided we adhere throughout the problem to the same unit

*Strictly, volume occupied by 1 kilogram of water at maximum density. A cubic decimeter of water at 4° C. weighs 0.999972 kilos. It is too late to correct the unfortunate discrepancy, which, however, is too trivial to affect ordinary practice.

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of comparison. Answers would then have to be given in decimals of an ounce.

No problems have been given in the comparison of one system with another, except in the one case of gas volumes. It is assumed that any reader having occasion to transform from metric to ordinary, or vice versa, can use the comparison factors, as given, for himself.

PROBLEMS IN THE METRIC SYSTEM.

(1) A rectangular tank is 4 meters long, 3 meters wide, and 2 meters deep. , How many liters of water will it contain?

Ans. 24,000 liters.

(2) How many grams in a metric ton? *Ans.* One million.

(3) How many cubic millimeters in a cubic meter?

Ans. One thousand million.

(4) What does a cubic millimeter of water weigh?

(1 milligram) *Ans.* 0.001 gram.

(5) A rectangular tank is 4 meters long, 3 meters broad, and contains 39,000 liters of water. How deep is the water?

Ans. 3.25 meters deep.

(6) What is the weight of a cylinder of copper (sp. gr. = 8.9) whose diameter is 4 centimeters and whose height is 30 centimeters? *Ans.* 3355.2288 grams.

(7) Cylindrical cistern is 4 meters deep and 3 meters diameter. How many liters will it hold? *Ans.* 28,274 liters.

(8) A hollow globe has internal diameter of one-fourth meter. How many liters will it hold? *Ans.* 8.1812 liters.

(9) What is the radius of a sphere, in millimeters, whose volume equals one liter? *Ans.* 62.03 millimeters.

(10) A cubical vessel holds 15.625 liters, what is length of the edge of the cube? Answer in centimeters.

Ans. 25 centimeters.

(11) If the edge of a cube equals 1, what will be radius of a sphere of equal volume? (See problem 9 above.) *Ans.* 0.6203.

(12) Cylinder of 6 centimeters internal diameter holds water to the height of 40 centimeters. What will the water weigh, assuming maximum density? *Ans.* 1130.976 grams.

(13) Same as 12, but mercury (sp. gr. = 13.59) substituted for water. What will its weight be in grams?

Ans. 15369.9638 grams.

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(14) Same dimensions, but hydrogen gas substituted, assumed weight per liter 0.09 gram. What weight? *Ans.* 0.1018 gram.

(15) We have one kilogram of each of the following metals, what volumes of each respectively? Answers in cubic centimeters.

Platinum.....sp. gr. = 21.5		Gold.....sp. gr. = 19.3	
Silver.....sp. gr. = 10.5		Aluminum..sp. gr. = 2.67	
Steel.....sp. gr. = 7.8		Lead .....sp. gr. = 11.4	
Copper.....sp. gr. = 8.9		Mercury....sp. gr. = 13.6	

Answers.

Platinum.....	46.51 c.c.	Gold.....	51.81 c.c.
Silver.....	95.24 c.c.	Aluminum.....374.53 c.c.	
Steel.....128.2	c.c.	Lead	87.72 c.c.
Copper.....112.36	c.c.	Mercury.....	73.53 c.c.

(16) A wire is 20 kilometers long, 2 mm. diameter. It is made of steel, sp. gr. 7.8. What is its weight in kilos?

Ans. 490.09 kilos.

(17) Sphere of silver (sp. gr. 10.5) weighs 43.9803 grams. What is radius of the sphere? *Ans.* 1 centimeter.

(18) How many cannon balls 2 decimeters in diameter can be made from 1 metric ton of iron (sp. gr. 7.8)?

Ans. 30 and a fraction.

ORDINARY SYSTEM.

Length.

12 inches = 1 foot.
3 feet = 1 yard = 36 inches.
63,360 inches = 5280 feet = 1760 yards = 1 mile.
(A "knot" is 1.152 statute miles = 6087 feet to nearest foot.)

Surface.

144 square inches = 1 square foot.
9 square feet = 1 square yard = 1296 square inches.
43,560 square feet = 1 acre = 4840 square yards.
640 acres = 1 square mile.

Volume or Capacity.

1728 cubic inches = 1 cubic foot.
231 cubic inches = 1 United States gallon.

(English or imperial gallon = 277.274 cubic inches, and taken in water at 62° Fahrenheit, weighs ten pounds or 70,000 grains.)

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A cubic foot of water at 4° C. weighs 62.42 lbs. avdp.
A cubic foot of ice weighs 58 lbs., and has a sp. gr. of 0.929.

Liquid Measure.

1 gallon = 4 quarts = 8 pints = 231 cubic inches.
United States gallon taken in water, contains 58,318 grains.

Weight.

We have three systems; common unit is the GRAIN, same in all three.

AVOIRDUPOIS.

1 pound = 16 ounces = 7,000 grains.
(2000 lbs. = 1 ton.)
1 ounce = 437½ grains.

TROY.

1 pound = 12 ounces = 5,760 grains.
1 ounce = 20 dwt. = 480 grains.
1 dwt. (pennyweight) = 24 grains.

(Troy weight is still used for the precious metals; comparison with avdp. is given below.)

APOTHECARIES.

20 grains	= 1 scruple.
3 scruples	= 1 dram.
8 drams	= 1 ounce.
12 ounces	= 1 pound.
1 ounce	= 480 grains.
1 pound	= 5,760 grains.

Further comparisons of the ordinary weight system show that:

1 troy pound = 13.166 avoirdupois ounces.
1 avdp. pound = 14.583 troy ounces.
1 avdp. ton = 29,166̇ troy ounces.

The number of troy ounces in the ordinary ton is useful in assaying. We weigh ore by the (avdp.) ton of 2000 lbs., but we weigh the precious metals by troy weight.

So when we speak of "so many ounces gold or silver to the ton" we are speaking of *troy* ounces in an *avoirdupois* ton.

See under "Assay weights."

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Comparisons of the ordinary and metric systems are annexed, but we repeat the precaution given at the outset, that the attempt to memorize the relations results in confusion for a beginner.

It is hardly necessary to extend comparisons to every subdivision of the metric, partly because there are conversions which are practically never made, but chiefly because having a "conversion" figure from ordinary into metric or the reverse, the change into other subdivisions of the metric is made by simply *shifting the decimal point.* Thus, if one inch is 25.4 millimeters, it is 2.54 centimeters, .254 decimeters, and 0.0254 meters.

CONVERSION OF METRIC TO ORDINARY STANDARDS AND THE REVERSE.

Length.

ORDINARY TO METRIC.

1 inch = 25.4 millimeters = 2.54 centimeters = 0.254 decimeters = .0254 meter.
1 foot = 304.8 millimeters = 30.48 centimeters = 3.048 decimeters = .3048 meter.
1 mile = 1.6093 kilometers = 1609.3 meters.

METRIC TO ORDINARY.

1 mm. = 0.03937; 1 cm. = 0.3937 inch.
1 dm. = 3.937; 1 meter = 39.371 inches.
1 meter = 3.2809 feet = 1.0936 yards.
1 kilometer = 3280.9 feet = 0.6214 mile.

Area.

ORDINARY TO METRIC.

1 square inch = 6.451 square centimeters.
1 sq. foot = 929.0 sq. centimeters = 0.0929 sq. meter.
1 acre = 4046.7 sq. meters = 0.40467 hectare.
1 sq. mile = 2.59 sq. kilometers.

METRIC TO ORDINARY.

1 square centimeter = 0.155 square inch.
1 sq. meter = 10.764 sq. feet.
1 hectare = 2.471 acres = 107,636.76 sq. feet.
1 sq. kilometer = 0.3861 sq. miles.

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Volume.

Ordinary to Metric.

1 cubic inch = 16.386 cubic centimeters (c.c.).
1 cubic foot = 28.315 liters. (We use 28.32 in conversion.)
1 gallon = 4.54346 liters.

Metric to Ordinary.

1 cubic centimeter (c.c.) = 0.06103 cubic inch.
1 liter = 61.027 cubic inches.
1 liter = 0.2201 gallon.
1 liter = 0.03532 cubic foot.

Weight.

Ordinary to Metric.

1 grain = 64.8 milligrams = 0.0648 gram.
1 oz. avdp. = 28.35 grams.
1 oz. troy = 31.1 grams.
1 lb. avdp. = 453.593 grams (or 0.453593 kilos).

Metric to Ordinary.

1 milligram = 0.01543 grain. (1 gram = 15.43 grains.)
1 kilogram = 2.20462 pounds.
1 metric ton = 2204.62 pounds.

---

1 ton (2000 lbs.) = 0.90719 metric tons.
1 metric ton = 1.10231 short tons (2000 lbs.).
1 cwt. (100 lbs.) = 45.35926 kilograms.
1 metric ton = 1000 kilograms.
1 short ton = 907.19 kilograms.

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SOME DATA IN MENSURATION OCCASIONALLY USED IN PHYSICAL CALCULATIONS.

Ratio of circumference to diameter of a circle is "π" = 3.1415926+. 3.1416 is a close approximation and is used in this work.

$$\frac{\pi}{2} = 1.5708. \quad \frac{\pi}{3} = 1.0472. \quad \frac{4\pi}{3} = 4.1888.$$

MULTIPLES OF "π."

1	3.1416	6	18.8496
2	6.2832	7	21.9912
3	9.4248	8	25.1328
4	12.5664	9	28.2744
5	15.7080		

Area of a circle = πR^2. (R = radius of the circle.)

Volume of a cylinder = $\pi R^2 \times H$. (R = radius of base, H = altitude.)

Surface of a sphere = $4\pi R^2$. (R = radius of the sphere.)

Volume of a sphere = $\frac{4\pi R^3}{3}$. $\left(i.e., \text{surface} \times \frac{R}{3}.\right)$

Examples.—(1) What is the volume of a cylinder 3 centimeters in diameter and 6 centimeters high?

$R = 1.5$. $R^2 = (1.5)^2 = 2.25$. $2.25 \times 6 = 13.50$ = Answer in cubic cm.

(2) What is volume of a sphere whose diameter is 9 meters?

$R = 4.5$. $R^3 = 91.125$. $91.125 \times 4.1888 = 381.7044$ cubic meters.

(3) What is the radius of a cylinder, whose volume is 100 cubic centimeters, and whose altitude is 5 centimeters?

$$V = \pi R^2 \times H$$

That is, since

$$V = 100 \text{ and } H = 5:$$

$100 = 3.1416\ R^2 \times 5$. $R^2 = 6.3662$ and $R = 2.5232$ centimeters.

(4) What is the radius of a sphere whose volume is 33.5104 c.c?

$$V = \frac{4\pi R^3}{3}$$

That is: $33.5104 = 4.1888\ R^3$

Hence $R^3 = 8$ and $R = 2$ (centimeters).

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(5) A cube has an edge of 10 centimeters.
A cylinder has diameter and altitude each 10 centimeters.
A sphere has diameter of 10 centimeters.

Find the volume of each. (Note that the cylinder is exactly inscribable in the cube, and the sphere in the cylinder.)

Answers. Volume of cube = 10^3 = 1000 cubic centimeters.
Volume of cylinder = 785.4 cubic centimeters.
Volume of sphere = 523.6 cubic centimeters.

(6) What is the radius of a sphere whose volume is equal to that of a cylinder of 5 cm. radius and 4 cm. altitude?

Volume of cylinder = $\pi 25 \times 4$; that is, 100π, or 314.16.

This, by the terms of the problem, must equal $\frac{4}{3}\pi R^3$; that is, 4.1888 R^3. R^3, therefore, is 75 and $R = \sqrt[3]{75} = 4.2172$ centimeters.

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CHEMICAL PROBLEMS.

Problem I.—To state the relative weights of constituents entering into a chemical reaction, the equation being given.

Example.—(Take atomic weights to nearest whole number.)

Zn	+	H_2SO_4	=	$ZnSO_4$	+ H_2
Zn = 65		H_2 = 2		Zn = 65	H_2 = 2
		S = 32		S = 32	
		O_4 = 64		O_4 = 64	
Summation (Zn) 65	+	(H_2SO_4) 98	=	($ZnSO_4$) 161	+ (H_2) 2

Answer.—Sixty-five parts by weight of zinc and ninety-eight parts of sulphuric acid produce one hundred and sixty-one parts of zinc sulphate and two parts of hydrogen.

We have then merely to add the atomic weights of the elements in each term to obtain the weights of the various substances. This is not, properly speaking, a "problem" at all, but only a restatement of the fact that the molecular weights of compounds are the sums of the atomic weights of the elements composing them, each weight being reckoned as many times as the subscripts indicate.

Note that the equation also illustrates the *Conservation of Mass:*

$$65+98=161+2$$

It is true that the "weights" in this illustration are merely "relative" expressions, but that does not affect the last statement, since any substitution of *actual weights*, in any unit of weight whatever, would bring about the same equation, provided the due proportions were maintained. This brings us to the first real "Stoichiometric" question.

Problem II.—(*a*) The *actual* weight of one substance entering into a chemical reaction being known, to determine the weight of any of the other substances, equation being given. ("Approximate" weights used throughout in Problem II.)

(As either element or compound may take part in the reaction, the word "substance" is used to indicate either. It is to

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be taken, however, to mean a "substance" of definite chemical composition and formula.)

Example:

$$KOH + NH_4Cl = KCl + H_2O + NH_3$$

If we have *one pound* of "caustic potash" (KOH), what will be the weights of ammonium chloride, potassium chloride, water and ammonia gas, respectively?

Solution.—The relative weights must be first set down as in Problem I. Now, since these weights are in fixed ratio, if one of them becomes concrete the others may at once be determined by a simple proportion. The same statement applies to so many other chemical problems, that it may be given as a perfectly general rule or principle, viz:

"Combining weights and actual weights are in the same ratio."

In forming the proportion, place the combining (molecular or atomic) weights in the first member, keeping second member for the known and unknown actual weights. Let the unknown come in as the last term.

K = 39	N = 14	K = 39	H_2 = 2	N = 14
O = 16	H_4 = 4	Cl = 35.5	O = 16	H_3 = 3
H = 1	Cl = 35.5			
KOH = 56	NH_4Cl = 53.5	KCl = 74.5	H_2O = 18	NH_3 = 17

Let it now be required to find the weight of potassium chloride (KCl).

$$KOH : KCl = KOH : KCl$$
$$56 : 74.5 = 1 : x \qquad x = 1.33.$$

Answer.—1.33 pounds of potassium chloride.

Repeating the rule: "Combining weight of potassium hydroxide is to combining weight of potassium chloride, as actual (known) weight of potassium hydroxide is to actual weight of potassium chloride."

In the same way we can get the weight of any other term of the equation.

$KOH : NH_4Cl = KOH : NH_4Cl$		
56 : 53.5 = 1 : 0.9554		(lbs.)
$KOH : NH_3 = KOH : NH_3$		
56 : 17 = 1 : 0.3036		(lbs.)
$KOH : H_2O = KOH : H_2O$		
56 : 18 = 1 : 0.3124		(lbs.)

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In short, each term of any chemical equation has a fixed numerical relation to each and every other term, whether the comparison be made in molecular or in actual weights.

We may now extend this illustration a little further. Let us suppose a *series* of reactions, as in the following equations:

$$H_2SO_4 + Zn = ZnSO_4 + H_2 \quad (1)$$
$$CuO + H_2 = Cu + H_2O \quad (2)$$
$$H_2O + SO_3 = H_2SO_4 \quad (3)$$
$$H_2SO_4 + Zn = ZnSO_4 + H_2 \quad (4)$$

Let the molecule H_2 be the same throughout these reactions, or, in actual weights, suppose the hydrogen to be always the same. Then will all the other molecules or weights be present in their fixed relative proportions. The SO_3 of (3) and the Zn of (1) or (4) are in the proportion of 80 to 65. Given any one term in the whole series, we can determine any other term.

Problem II.—(*b*) In a series of connected reactions (equations being given) to determine the weight of any product (final or intermediate) from known weight of any one term, without calculating the intermediate terms.

Solution.—This is a mere variant, and a very trivial one, from Problem II (*a*). Method is exactly the same.

Example:

$$4NaCl + 4H_2SO_4 = 4NaHSO_4 + 4HCl \quad (1)$$
$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2 \quad (2)$$

We have ten pounds of salt (NaCl) in (1); what weight of chlorine gas will be produced in (2)?

$$4NaCl = (23 + 35.5) \times 4 = 234$$
$$Cl_2 = 35.5 \times 2 = 71$$

$$4NaCl : Cl_2 = 4NaCl : Cl_2$$
$$234 : 71 = 10 : x = 3.034 \textit{ Ans.}$$

We could go from term to term, calculating the weight of each and every compound in succession. This indeed would be necessary if the calculation be supposed to indicate some practical manufacturing process. In such a case we should compute the sulphuric acid needed, and the manganese dioxide. So far as the weight of the final product is concerned, such procedure is quite needless.

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Problem II.—(*c*) Find weight of a substance "*B*" chemically equivalent to a given weight of a substance "*A*," according to a given or required formula.

The variation from the other forms is very trivial. No equation, however, need be written in this case. It is another application of "Combining and actual weights in the same ratio."

Examples.—(*a*) We have 3 per cent. of copper in an ore. How much sulphur will it take to bring it into matte in the form of Cu_2S?

This ratio being often called for in metallurgical calculations, it is usual to assume copper as four times the weight of the sulphur in the combination Cu_2S. This is merely assuming that the atomic weights are 64 and 32 instead of 63.57 and 32.07 respectively.

We have then

$$\begin{array}{llllllll} Cu_2 & : S & = Cu_2 & : S & = Cu_2 & : S \\ 128 & : 32 = & 4 & : 1 & = & 3 & : 0.75 \end{array}$$

So that in one hundred lbs. of ore we should use 0.75 lbs. of sulphur in the formation of the matte which carried all of its copper.

(*b*) We have 20 lbs. of silica. What weight of lime (CaO) is needed to combine with it, so as to form Ca_2SiO_4?

This formula separates into 2CaO and SiO_2. We now have:

SiO_2	: 2CaO	= silica (lbs.)	: lime (lbs.)
60	: 112	= 20	: 37.66

(*c*) 100 lbs. of PbS is roasted to $PbSO_4$. What is the gain in weight?

PbS	: $PbSO_4$	= lbs. sulphide	: lbs. sulphate
239	: 303	= 100	: 126.7

(Gain = 26.7 lbs.)

There are cases in which the statement may be facilitated by writing an equation of reaction, *e.g.:*

(*d*) How much potassium cyanide will be destroyed by one pound of sulphuric acid? The equation of this reaction (for solutions) would be:

$$KCy + H_2SO_4 = KHSO_4 + HCy \quad (Cy = 26)$$

Then:

H_2SO_4	: KCy	= lbs. acid	: lbs. cyanide
98	: 65	= 1	: 0.66

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A variety of stoichiometrical problems, many of which have metallurgical applications, come under the elementary principle illustrated in these variants of Problem II.

As part of this volume is devoted to metallurgical calculations, some problems preliminary to actual furnace or slag calculations are appended, together with others of a more general kind.

(*e*) An ore contains by analysis:

FeS_2	48.00 per cent.
ZnS	24.25 per cent.
Silica	27.75 per cent.
Total	100.00 per cent.

It is roasted, with reactions as below:

$$4FeS_2 + 11\,O_2 = 2Fe_2O_3 + 8SO_2$$
$$ZnS + 2\,O_2 = ZnSO_4$$

Suppose one ton of the ore to be treated. What is weight of the product after roasting? *Ans.* No change in weight.

(*f*) $$2KNO_3 + H_2SO_4 = K_2SO_4 + 2HNO_3$$

(Production of nitric acid from potassium nitrate and sulphuric acid.)

Take 350 grams of the nitrate, what weight of sulphuric acid is required? *Ans.* 169.8 grams.

(*g*) $$Sn + 4HNO_3 = SnO_2 + 4NO_2 + 2H_2O$$

Seven lbs. of the binoxide were produced, what weight of tin was taken? *Ans.* 5.517 lbs.

(*h*) $$PBr_3 + 3H_2O = H_3PO_3 + 3HBr$$
$$3HBr + 3AgNO_3 = 3HNO_3 + 3AgBr$$

Phosphorus tribromide is decomposed by water, and then precipitated with silver nitrate. If 3.3 grams of the tribromide were taken, what is weight of the silver bromide?

Ans. 6.87 grams.

(*i*) We have ore with 30 per cent. silica which is to be combined with enough ferrous oxide to form FeO, SiO_2. What weight of Fe_2O_3 must be added to effect this? Weight of ore one hundred lbs.

$$60 : 72 = 30 : 36$$

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We require therefore 36 lbs. of ferrous oxide. Ferric oxide (Fe_2O_3) contains 90 per cent. ferrous oxide by formula. Hence:

$$\frac{36}{.9} = 40 = \text{required lbs. of ferric oxide}$$

(*j*) Ore contains 40 per cent. lead sulphide (PbS). Roasted, this becomes a mixture of lead oxide (PbO) and lead sulphate ($PbSO_4$). One-half of the lead in the ore goes to each form. Take 100 lbs. of ore, what will be the respective weights of oxide and sulphate produced?

Ans. PbO, 18.66; $PbSO_4$, 25.36 lbs.

(*k*) $$4FeS_2 + 11\,O_2 = 2Fe_2O_3 + 8SO_2$$

Three tons of pyrite are roasted to ferric oxide. What will be the weight of the latter? *Ans.* 2 tons.

(*l*) $$2KI + MnO_2 + 2H_2SO_4 = K_2SO_4 + MnSO_4 + 2H_2O + I_2$$

If the iodine produced weighed 9.071 what weight of potassium iodide was taken? *Ans.* 11.857.

(*m*) $$S_2 + 3\,O_2 + 2H_2O = 2H_2SO_4$$

This is an outline of the process of manufacturing sulphuric acid. If we take 500 lbs. of sulphur, what weight of sulphuric acid? *Ans.* 1531 lbs.

(*n*) Tri-calcic phosphate has the formula $Ca_3(PO_4)_2$. What weight of it contains 20 lbs. of phosphorus? *Ans.* 100 lbs.

(*o*) $$2As_2 + 3\,O_2 = 2As_2O_3$$

Take 1350 grams metallic arsenic, what weight of trioxide is obtained? *Ans.* 1782 grams.

(*p*) $$2Ca\,(PO_3)_2 + 5C = 5CO + Ca_2P_2O_7 + 2P$$

Calcium metaphosphate heated with charcoal produces calcium pyrophosphate and phosphorus.

Taking 31 grams of the metaphosphate, what weight of phosphorus? *Ans.* 4.85 grams.

(*q*) $$CaSO_4 + BaCl_2 = CaCl_2 + BaSO_4$$

The $BaSO_4$ resulting from this reaction weighed 11.65. What weight of calcic sulphate was taken? *Ans.* 6.8.

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(*r*)
$$\begin{aligned} PCl_5 + 4H_2O &= H_3PO_4 + 5HCl \\ 5HCl + 5AgNO_3 &= 5HNO_3 + 5AgCl \\ 5AgCl &= 5Ag + 5Cl \end{aligned}$$

Weight of the silver from these reactions was 67.5 grams, find weight of the phosphoric acid. *Ans.* 12.25 grams.

(*s*) $MgCO_3 + H_2SO_4 + 6H_2O = MgSO_4, 7H_2O + CO_2$

Limestone contains 12 per cent. magnesium carbonate. Take forty pounds of it, how many pounds of the crystallized sulphate? *Ans.* 14.05 lbs.

(*t*) $Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2$ (Cu = 64)

The SO_2 gas weighs 7.11 grams. What weights of copper and of sulphuric acid were taken?

Ans. Copper 7.11 lbs. Acid 21.73 lbs.

(*u*) $4FeS_2 + 8H_2O + 15O_2 = 2Fe_2O_3 + 8H_2SO_4$

This represents in outline the production of sulphuric acid from pyrite. Take 1000 lbs. of pyrite, what weight of sulphuric acid is obtained? *Ans.* 1633 lbs.

(*v*) $NaNO_3 + KCl = NaCl + KNO_3$

Interchange of bases and acid radicals in the manufacture of potassium nitrate (saltpeter) from sodium nitrate and potassium chloride.

Take 17 lbs. of sodium nitrate. What weight must we add of potassium chloride, and what will be weight of potassium nitrate? *Ans.* 14.9 lbs. potassium chloride. 20.2 lbs. nitrate.

(*w*) $Na_2CO_3 + 2C = 3CO + Na_2$

From this operation 43.4 lbs. of sodium were produced. How many lbs. of sodium carbonate were taken?

Ans. 100 lbs.

(*x*) $CaCO_3 = CaO + CO_2$

This represents the burning of limestone to produce quick-lime. If we want 100 lbs. quick-lime (CaO) what weight must we take of the limestone? *Ans.* 178.6 lbs.

(*y*) $Fe_2O_3 + 3C = 3CO + Fe_2$

Hematite (Fe_2O_3) is reduced in the blast furnace in about this ratio to the carbon introduced (theoretically).

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Suppose the coke to contain ninety per cent. of carbon, how many pounds of it will reduce 432 lbs. of hematite to metallic iron? *Ans.* 108 lbs.

(*z*) $(NH_4)_2 PtCl_6$. This salt (chloroplatinate of ammonium) is decomposed on heating, leaving behind only its platinum. Wishing to obtain 100 grams of the metal, what weight of the salt must we take? *Ans.* 227.8 grams.

Many examples involving this principle will be found under other headings. They are not placed here, because the above cases introduce no considerations but weight, while the slightly more complex problems under other captions include gas volumes, thermometer and barometer and atomic weight determinations.

DEDUCTION OF ANALYSIS FROM FORMULA.

Problem III.—(*a*) Given the formula of a chemical compound, to deduce its analysis, or composition expressed in percentages.

Before illustrating the working of this very simple problem, we call attention to the various possible subdivisions we may make in a compound.

Take $PbSO_4$. It may be divided into its three elements, in which case we should get its percentages of lead, sulphur and oxygen, respectively, which must sum to 100. It might be divided into the metal lead and the anion SO_4, which is merely a negative radical with no independent existence as a compound. It might be more rationally divided into PbO and SO_3, and it was in fact so written in the days of the long prevalent "dualistic" nomenclature and symbolism: PbO, SO_3. The character of the subdivision will depend upon the purpose or point of view to be subserved, but whatever division be called for, the method of solution is not altered in the least.

The molecular weight (using nearest units of atomic weights) is 303, *i.e.*,

Pb	=	207	
S	=	32	
O_4	=	64	Total 303

The number 303 must be used in any case. If we are to get the percentage of lead we compare it with 207. If per cent. of PbO is required we compare it with 223 (Pb, 207 + O,16) and so on for any combination.

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The student should realize that the subdivisions of compounds as expressed by formulæ and as set forth in analyses sometimes differ considerably. Binaries with only one atom of each element in the formula admit of only one subdivision; many other substances (compounds) have to be divided according to the demands of special requirements.

In the case of the hydroxides they may usually be divided into the oxide and water. Example:

$$Fe_2(OH)_6 = Fe_2O_3 + 3H_2O$$

Another familiar instance is found in the carbonates which are always subdivided into the oxide and CO_2, *e.g.*,

$$CaCO_3 = CaO + CO_2$$

The same is true of all the amphid salts. They must often be separated, in an analytical statement, into oxide and anhydride.

The beginner in analytical chemistry should be made aware that although the "dualistic" nomenclature is about dead, it survives after a fashion in the summations of many analyses.

Thus, in the now obsolete method, we once wrote $3CaO,P_2O_5$. We now write $Ca_3(PO_4)_2$. But in summing an analysis which showed lime and phosphates, we should have to write CaO and P_2O_5 as constituents for summation.

We mentioned in the introduction that a difficulty sometimes arose by forgetting to double a symbol in making a formulistic transposition. We have here a cognate case, though not of exactly the same description.

Suppose an alum is to be analysed, general formula $AlK(SO_4)_2 + 12H_2O$. On attempting to "adjudicate" such an expression, or to write its "analysis" by percentages, we find we cannot do so rationally, without doubling first, and then separating into the well-known proximate constituents, thus:

$$Al_2(SO_4)_3 + K_2SO_4 + 24H_2O$$

This serves to show the separate relations of the metals to the sulphuric acid anion, but for analytical statement we would have to go further, summing the oxides and of necessity the anhydrides.

$$Al_2O_3, 3SO_3 + K_2O, SO_3 + 24H_2O$$

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This is the full "dualistic" form, and for *analytical* statement the two portions of anhydride (SO_3) would have to be put under the same heading constituting one of the "percentages" of the complete analysis.

In metallurgical formulæ the student may often have occasion to transform a silicate from modern into ancient form of statement, for the latter survives in the consideration of slag silicates.

Example.—$Al_4Si_3O_{12}$. It is not easy to recognize the class (metallurgically) to which this silicate belongs, without taking out the silica first. Since there are three atoms of silicon we "take out" $3SiO_2$, which leaves Al_4O_6, quickly recognized as $2Al_2O_3$. ("Singulo silicate.")

The fact that the old system is obsolete might seem a sufficient reason for excluding all mention of it from this work. But although extinct in form, "the fact remains" that there are numerous cases in which separation into the old proximates is necessary.*

The student must then understand that in the computation of percentages something more is often required than the mere estimation, element by element. These cautions, already somewhat extended, will receive illustration in a number of examples.

We now turn to the statement of Problem III (*a*) as in the heading.

We have only to remember that each symbol represents a weight proportional to the atomic weight. Then:

"*The molecular weight of the compound is to the atomic (or molecular) weight of a given constituent, as* 100 *is to the percentage of the constituent in question.*"

Examples.—(*a*) Find percentage composition of pyrite, FeS_2.

Atomic weight of iron	56
Molecular weight of two sulphurs	64
Molecular weight of FeS_2	120

*The subject is expanded for the benefit of beginners. Those who think too much space has been given to an extremely simple sub-topic are not far mistaken. They are recommended, however, to take a course *as instructor* in the subject. The author has had trouble enough for three lectures in the above elementary exposition.

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Now apply the rule, putting the "theoretical" weights in the first member of your proportion. As a rule, let the "unknown" come in as fourth term.

For iron.....120 : 56 = 100 : x. x = 46.66 = per cent. iron.
For sulphur...120 : 64 = 100 : y. y = 53.33 = per cent. sulphur.

Proof : Total.....99.99 per cent.

(*b*) Find composition of calcite, $CaCO_3$, expressed in percentages of lime (CaO) and carbon dioxide (CO_2).

CaO = 40 + 16 = 56. CO_2 = 12 + 32 = 44. Total = 100.

It happens that the molecular weight of the compound is just 100. It is evident then that the figures for the partial molecular weights are the same as "percentages."

Ans. CaO, 56 per cent., and CO_2, 44 per cent.

(*c*) Find percentage composition of magnesium pyrophosphate $Mg_2P_2O_7$, expressed as MgO and P_2O_5. Also find percentage of phosphorus.

Remember here that the MgO is *formulistically* Mg_2O_2, or rather, 2MgO. Also, that the phosphorus must be figured as P_2 as in the formula, not as "P."

Ans. 2MgO = 36.24 per cent. P_2O_5 = 63.76 per cent. P_2 = 27.84 per cent.

(*d*) Find composition of the silicate $Ca_2SiO_4 + Fe_2SiO_4$, expressed in terms of CaO, FeO and SiO_2.

Evidently there are two molecules of CaO and two of FeO. After subtracting these, we find remaining Si_2O_4, that is, $2SiO_2$.

We now tabulate the various molecular weights and sum up. It is hardly necessary to "spread" all of these in the form of the complete proportion. The student will rapidly learn to dispense with that form in many cases. *He will use it in fact*, but will hardly trouble himself to write the proportional equation out in full.

$2SiO_2$ = 120	$\frac{120 \times 100}{376}$	= 31.91 = per cent. of SiO_2
2CaO = 112	$\frac{112 \times 100}{376}$	= 29.78 = per cent. of CaO
2FeO = 144	$\frac{144 \times 100}{376}$	= 38.30 = per cent. of FeO
Total.....376		99.99 = Total per cent. (Proof.)

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(*e*) Bone ash has the average composition, formulistically, $CaCO_3$, $3Ca_3(PO_4)_2$.

Find the percentage composition:

(1) By elements.

(2) As oxides and anhydrides.

(3) As salts (*i.e.*, carbonates and phosphates).

Method (operations not given in detail).—The phosphate symbols are to be extended, *i.e.*, multiplied out, which gives us $Ca_9P_6O_{24}$. Take out all the CaO, *i.e.*, since there are 9 times Ca subtract 9 oxygens also. This leaves P_6O_{15}, that is, $3P_2O_5$. Treat the $CaCO_3$ in the same way. Thus we easily get molecular weights of the whole and of each part, in all the three ways.

Answers:

AS ELEMENTS.		AS OXIDES, ETC.	
Carbon.....	1.16 per cent.	CaO....	54.37 per cent.
Calcium.....	38.84 per cent.	CO_2....	4.27 per cent.
Phosphorus.....	18.06 per cent.	P_2O_5 ...	41.36 per cent.
Oxygen.....	41.94 per cent.		
	100.00 per cent.		100.00 per cent.

AS SALTS.

$CaCO_3$.....	9.71 per cent.
$Ca_3(PO_4)_2$	90.29 per cent.
	100.00 per cent.

This problem being very simple, examples are not extended. However, the table of per cent. composition (III) and the table of chemical factors (II), especially the first, contain as many "problems" in this line as there are substances given. The same may be said of the table of compositions in relation to the next problem, viz: the derivation of formula from analysis.

Before dropping the problem, we may repeat what has been said elsewhere as to the difference between strictly formulistic and analytical subdivision of proximates.* Generally we may say that a statement of composition would hardly be recognized as "analytical" which contained as a percentage constituent a radical or "ion" not susceptible of actual separation. It is just as easy to "figure out" such a percentage as any other, but that is no justification for doing so.

*If water be present, state its percentage as such, not separating it into oxygen and hydrogen.

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For example, the very familiar anion SO_4 has no real existence as a *substance*, however real it is as existing in a compound. Neither has the excessively frequent "OH"—hydroxyl.

Problem III.—(*b*) To construct a table of chemical factors. (Table II.)

The "factors" used in the calculation of chemical analyses are useful both for acceleration of the work and for the avoidance of error.

Suppose we are making a series of determinations of tin in tin alloys. The substance *weighed* will always be tin binoxide (SnO_2). This we know contains: Sn = 119 and O_2 = 32 as to atomic weights. Thus we have the proportion, calling the known weight "*a*" and the weight of tin (sought) "*x*:"

$$\begin{array}{lll} SnO_2 : Sn & = SnO_2 \text{ found} : Sn \text{ sought.} \\ 151 : 119 & = a : x \end{array}$$

$$x = \frac{a \times 119}{151}$$

Evidently the fraction $\frac{119}{151}$ will always enter this particular computation, and be reduced to a factor in decimals. Performing the indicated division we find this factor to be 0.7881. That is, *any given weight of tin binoxide multiplied by this factor gives the weight of the tin which it contains.* If we have taken one gram for analysis the result will be the figures expressing percentage as well as actual weight.

Example.—We take one gram for analysis, and find 0.1325 SnO_2. This, multiplied by factor 0.7881, gives 0.1044, which is the weight of the tin in decimals of a gram. But the figures of course express the percentage also. *We have only to multiply by* 100, *writing them* 10.44, to get the ordinary expression for percentage, with 100 instead of unity as the total.

The "factors" are in short simply the percentages of the required element in the given compound, divided by 100.

In case a multiple or sub-multiple of a gram has been taken—or, as was once the regular practice, a wholly irregular and chance-selected weight, the operation of ascertaining the percentage is lengthened. Irregular weights are now rarely taken, and indeed only as a matter of necessity. It sometimes happens that a very hard metal is brought to the chemist in coarse pieces instead of filings. It is usually much easier to weigh out an "irregular" quantity and perform the necessary extra calcu-

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lations than to try to reduce the metal to a powder fine enough for taking a weight of it to the exact gram.

As we always want an expression in percentage, we must somewhere in our calculations divide weight found, *times* 100, by total weight. This may be accomplished without going through this operation literally, but the operation must be there in some shape.

When any quantity other than a gram has been taken for analysis, the easiest way to calculate is simply to divide the weight found by the weight taken. The quotient is the weight that would have been found *had one gram been taken originally.*

Example.—We take one gram of an ore for analysis and find for magnesium the precipitate $Mg_2P_2O_7$ weighing 0.2246. Required, percentage of MgO. We multiply by 0.3622 (see Table II) and find 0.0814 or 8.14 per cent.

Suppose we had taken 1.5 gram instead of 1 gram. Then the $Mg_2P_2O_7$ would have weighed 1.5 times more, or 0.3369 gram. Dividing by 1.5 we reduce to the figure 0.2246, *i.e.*, the figure obtained when we take 1 gram.

Similarly, had we taken 0.5 gram we would have found 0.1123 as weight of $Mg_2P_2O_7$. Divide by 0.5 and we again get the figure 0.2246.

Exercises on the use of the table of factors, both for one gram and for irregular weights, are given below.

The student should observe that, as a rule, the smaller the proportion of an element "sought" in the compound weighed, the more accurate the determination so far as concerns the sources of error derived from ordinary loss or gain.

Assume two cases. In the first we are to determine bismuth from the weight of Bi_2O_3. In the second we are to determine sulphur from the weight of $BaSO_4$. Let us suppose that the weight of each (derived from original portion taken of one gram in each case) comes out the same (0.0700 gram). If from each analysis we have lost the same weight of precipitate, say five milligrams (*i.e.*, alike of Bi_2O_3 and $BaSO_4$), a very simple calculation will show that the error in bismuth will be .0045 or 0.45 per cent., while that of the sulphur will be only 0.0007 or 0.07 per cent.

Deduction of weight *sought* from weight of another substance *found* being the commonest of all laboratory calculations, this

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problem has been frequently introduced as part of the necessary calculation in other problems, such as computation of atomic weights, excess and deficiency, etc.

The logarithms of these factors are often used, and are as usual annexed to them in the table. In working a series of the same determinations it is convenient to have the log. of the factor which is being so constantly used ready on the computation paper, so that it remains only to take out the log. of the weight which is to be multiplied. Some persons, however, find it easier to multiply four digits by four others than to "take out" from the logarithmic table. With practice, the latter becomes the quicker.

EXERCISES IN THE USE OF CHEMICAL FACTORS (TABLE II).
WEIGHT TAKEN ONE GRAM.

Substance Weighed.	Weight Found.	Substance Sought.	Percentage.
$PbSO_4$	0.2350	Pb	16.05
Fe_2O_3	0.9120	Fe	63.78
ZnO	0.5480	Zn	44.07
$Mn_2P_2O_7$	0.0260	MnO	1.30
Cu_2S	0.5252	Cu	41.94
AgCl	0.1234	Ag	9.29
$BaSO_4$	0.5000	SO_3	17.15
Bi_2O_3	0.1111	Bi	9.96
N	0.1326	NH_3	16.12
$Mg_2P_2O_7$	0.2732	MgO	9.90
ZnS	0.8432	Zn	56.66
$Pt[(NH_4)_2PtCl_6]$	0.1214	N	1.74
$BaSO_4$	0.4321	S	5.93
SiO_2	0.1233	Si	5.79
PbS	0.2324	Pb	20.12
$BaSO_4$	0.3734	BaO	24.53
CO_2	0.0770	C	2.10
$Mg_2P_2O_7$	0.0821	P_2O_5	5.24
Ag (from Ag_3AsO_4)	1.0000	As	23.17
Sb_2S_3	0.3642	Sb	26.01
SnO_2	0.6140	Sn	48.39
KCl	0.0378	K_2O	2.39
NiO	0.0414	Ni	3.31
Cr_2O_3	0.0762	Cr	5.22
NaCl	0.3611	Na_2O	19.15
$CaSO_4$	0.5406	CaO	22.27

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EXERCISES IN THE USE OF CHEMICAL FACTORS (TABLE II).
IRREGULAR WEIGHTS.

Weight Taken.	Found.	Weight Found.	Sought.	Percentage.
(*a*) 0.435	KCl	0.102	K_2O	14.81
(*b*) 1.234	$CaSO_4$	0.064	CaO	2.14
(*c*) 0.800	CaO	0.328	$CaCO_3$	73.16
(*d*) 0.412	Pt	0.414	N	14.44
(*e*) 2.500	Pt	0.284	NH_3	1.99
(*f*) 0.886	$BaSO_4$	0.441	BaO	32.70
(*g*) 0.765	$BaSO_4$	0.202	S	3.63
(*h*) 1.500	$BaSO_4$	0.606	SO_3	13.85
(*i*) 0.750	Fe_2O_3	0.302	Fe	28.16
(*j*) 0.250	Fe_2O_3	0.072	FeS_2	43.28
(*k*) 1.200	ZnO	0.840	Zn	56.29
(*l*) 0.500	ZnS	0.225	Zn	30.24
(*m*) 3.000	SnO_2	0.488	Sn	12.82
(*n*) 2.750	Sb_2S_3	1.668	Sb	43.32
(*o*) 0.400	$Mg_2P_2O_7$	0.186	P	12.95
(*p*) 5.000	$Mg_2P_2O_7$	0.026	P_2O_5	0.332
(*q*) 1.275	$Mn_2P_2O_7$	0.456	MnO	17.88
(*r*) 1.400	Cu_2S	0.233	Cu	13.29
(*s*) 3.500	CuO	0.998	Cu	22.78
(*t*) 0.428	$AgCl$	0.187	Ag	32.88
(*u*) 0.924	$AgCl$	0.296	Cl	7.92
(*v*) 0.756	SiO_2	0.700	Si	43.45
(*w*) 0.280	$PbSO_4$	0.300	Pb	73.19
(*x*) 0.350	Bi_2O_3	0.062	Bi	15.88
(*y*) 0.275	$NaCl$	0.106	Na_2O	20.44
(*z*) 0.892	$Mg_2P_2O_7$	0.099	MgO	4.02

Problem III.—(*c*) To reduce any summation to the basis of percentage, it is only necessary to proceed exactly as in obtaining an analysis from a formula.

Example.—Calculation of a slag shows us that we may expect total weight from a given charge, of 450 lbs. of slag, distributed as follows:

Silica	180 lbs.
Alumina	90 lbs.
Lime	160 lbs.
Magnesia	20 lbs.
Total weight	450 lbs.

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It being now required that the composition of this slag should be represented by an analytical statement in the usual form, *i.e.*, summation by percentage, the procedure is obvious.

$$\text{Silica} = \frac{18000}{450} = 40.00 \text{ per cent.}$$

$$\text{Alumina} = \frac{9000}{450} = 20.00 \text{ per cent.}$$

$$\text{Lime} = \frac{16000}{450} = 35.56 \text{ per cent.}$$

$$\text{Magnesia} = \frac{2000}{450} = 4.44 \text{ per cent.}$$

$$100.00 \text{ per cent.}$$

These are simply proportions abbreviated, *e.g.*,

For silica, 450 : 180 = 100 : 40, etc.

The process is too elementary for examples to be added.

DEDUCTION OF FORMULA FROM ANALYSIS.

Problem IV.—Given the analysis of a chemical compound, to derive its formula.

The analysis alone does not necessarily give us all the data for the formula. We may always obtain a provisional formula, which is correct as to *relative* numbers of atoms of the various elements.

In metallurgical cases, as we know all the ordinary compounds, and the valencies of the usual elements entering into such compounds, the provisional formula is almost invariably the correct one.

The subject is not enlarged upon, as much that is said under the heading of "Atomic and Molecular Weights" applies as well.

Method.—By dividing each percentage figure by the atomic weight of the element, we obtain numbers which stand in the numerical ratios of the respective numbers of atoms. Reducing these numbers to their lowest proportional terms, by G. C. D., we obtain the simplest expression for the provisional formula.

Examples.—(*a*) An oxide of iron contains: iron, 70 per cent.; oxygen, 30 per cent. Find its formula.

Divide each percentage by corresponding atomic weight.

$$\frac{70}{56} = 1.250 \text{ for iron; and } \frac{30}{16} = 1.875 \text{ for oxygen.}$$

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(The decimal points may be omitted, provided attention be paid to the number of places, so as not to accidentally multiply one number by ten or more, so we call these numbers 1250 and 1875 respectively.)

But 1250 and 1875 are as 2 : 3. *Ans.* Fe_2O_3.

It is evident that the arithmetical process is unable to answer the question "why not 4 and 6 as well as 2 and 3?" In fact several formulæ have been written in more than one way, *e.g.*, Fe_2Cl_6 otherwise $FeCl_3$.

Evidently, in the above rule, we may have instead of "element" any subcompound or radical, if we choose so to state the analysis.

It is only in formulæ of exceptional complexity that the simplest ratio will not suggest itself at sight, when the first quotients have been obtained, so that we rarely have to apply the formal G. C. D. rule.

(*b*) A slag analyzes as below:

Silica (SiO_2)	48.39 per cent.
Ferrous oxide (FeO)	29.03 per cent.
Lime (CaO)	22.58 per cent.
	100.00 per cent.

Find formula expressed as separate silicates of iron and lime.

Applied as in the first example, we find as first quotients:

$$SiO_2 = \frac{48.39}{60} = .806. \quad FeO = \frac{29.03}{72} = .403. \quad CaO = \frac{22.58}{56} = .403.$$

No operation is needed to find the ratio 2 : 1 : 1.

There are then two molecules of silica, one each of the bases, hence formula: $CaOSiO_2 + FeOSiO_2$. ("Bisilicate."*)

(*c*) A mineral contains:

Sodium	32.86 per cent.
Aluminum	12.86 per cent.
Fluorine	54.28 per cent.
	100.00 per cent.

Find its formula.

$$Na = \frac{32.86}{23} = 1.429. \quad Al = \frac{12.68}{27} = 0.4763. \quad F = \frac{54.28}{19} = 2.857.$$

* *I.e.*, oxygen in SiO_2 = twice oxygen in base. The relation is seen at a glance when the old "dualistic" form is retained.

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These quotients readily give the ratios 3 : 1 : 6. Na_3AlF_6.

(*d*) A salt contains by analysis:

Sodium	16.20 per cent.
Tin	41.56 per cent.
Oxygen	16.90 per cent.
Water	25.34 per cent.
	100.00 per cent.

Find formula. *Ans.* $Na_2SnO_3, 4H_2O$.

Taking the above formula what would be the exact corresponding analysis?

Ans.

Sodium	16.17 per cent.
Tin	41.73 per cent.
Oxygen	16.83 per cent.
Water	25.27 per cent.
	100.00 per cent.

(*e*) Analysis:

Nickel	31.15 per cent.
Hydrogen	3.18 per cent.
Nitrogen	14.84 per cent.
Sulphur	16.95 per cent.
Oxygen	33.88 per cent.
	100.00 per cent.

Find formula. *Ans.* $(NH_3)_2NiSO_4$.

(*f*) Analysis:

Phosphorus	24.62 per cent.
Oxygen	19.06 per cent.
Chlorine	56.32 per cent.
	100.00 per cent.

Find formula. *Ans.* $P_2O_3Cl_4$.

Note that in this case our least quotient used as unity would give us a *fractional subscript*. We therefore double every number, with the above result.

(*g*) A compound yields by analysis:

Copper	29.54 per cent.
Iron	13.07 per cent.
Tin	27.53 per cent.
Sulphur	29.86 per cent.
	100.00 per cent.

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Find the formula. The quotients in this case can be read off into their simplest terms at sight. *Ans.* Cu_2FeSnS_4.

(*h*) Analysis:

Carbon	3.05 per cent.
Hydrogen	0.25 per cent.
Iodine	96.70 per cent.
	100.00 per cent.

Find formula. *Ans.* CHI_3. (Iodoform.)

The last problem suggests a point important in practice. The principle is simple enough, but the working out of a formula by this method presupposes almost absolute accuracy in the analysis, a condition rarely present.

In cases of very simple composition, and of substances *whose atomic weights do not differ very largely*, ordinary analytical accuracy or even fair approximations would lead to correct formulæ. It is otherwise in complex formulæ, especially where there is great discrepancy (as in "*h*") between atomic weights of the constituents.

Let us suppose we have an analysis of pyrite, which reads as follows:

Iron	47.50 per cent.
Sulphur	52.50 per cent.
	100.00 per cent.

the correct analysis being:

Iron	46.57 per cent.
Sulphur	53.43 per cent.
	100.00 per cent.

The difference is quite outside of allowable error in an analysis of this character. Yet, if we apply the rule, we shall find the formula FeS_2, for our quotients will be 85 and 164, numbers far too close to the ratio of 1 : 2 to admit any other interpretation.

Let us next look at the analysis of iodoform. Hydrogen is not only the element of least atomic weight, but it has by far the least percentage in the composition, and is also the most difficult to determine with accuracy. Let the analysis read:

Carbon	3.10 per cent.
Hydrogen	.20 per cent.
Iodine	96.70 per cent.
	100.00 per cent.

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As to total error *reckoned on the composition*, the error in hydrogen is hardly more than $\frac{1}{20}$ of that in the pyrite analysis. But as to the ratio, it puts it out very badly, giving as trial subscripts 258, 200 and 761 for C, H and I respectively, variation enough to throw doubt upon the identity of the numbers representing atoms of carbon and hydrogen, and in fact making the formula $C_5H_4I_{15}$ look far more probable, *arithmetically speaking*, than CHI_3.

In cases similar to this one, it is safer not to adopt the lowest ratio number as unity. This is in fact erroneous both in arithmetical principle and in chemical probability, *i.e.*, as regards greatest chance of analytical error. The latter consideration hardly belongs to a discussion of stoichiometric relations, but we may point out that a small percentage is more liable to proportional errors in laboratory manipulation.

Choose, then, for the standard of comparison (after the divisions have been made), an element whose determination is probably the most accurate in character, especially if its ratio number (quotient) be relatively large.

The subject of mineral analysis and of the determination of formulæ is not pursued further here, as it is thought to be hardly a fit topic for a text devoted to elements. It is, however, susceptible of considerable expansion, and advanced works on mineralogy discuss it at length.

Few examples are given under this heading, because Tables II and III are really problems and answers, which the student may take up and verify ad libitum. Obviously the data in them may be worked either way, *i.e.*, either the analysis assumed and the formula worked out, or vice versa.

As in the case of certain slag problems, treated in Part II, it is not essential for the working of a formula that the composition should be expressed *in the form of an analysis, summing to* 100 *per cent.* For if the expression for the composition indicates the *proper ratios* of the various elements, it is evident that these must come to the same simplified expression at last as the ratios expressed by the analysis.

Problem "*f*" above illustrates a case which may often occur. When reduction to lowest terms gives a fraction, multiply by a number which will clear of that fraction, raising, of course, subscript of every other element.

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Problem IV. (*a*) *Other methods of solution.*—All the methods are based upon the division by atomic weights, but the quotients may be treated somewhat differently from above rule, which practically amounts in most cases to the division of all the quotients by the least one.

We may take any one quotient and write instead of it some number rich in factors, like 60 for example. Raise the other quotients in the same proportion. ($q : 60 = q^1 : x$) Now divide by the highest common factor. This, however, is no great variant from the first method.

Example (1).—Analysis:

Nitrogen	6.32 per cent.
Platinum	43.92 per cent.
Chlorine	47.95 per cent.
Hydrogen	1.81 per cent.
	100.00 per cent.

Quotients : nitrogen = 0.451; hydrogen = 1.81; platinum = 0.225; and chlorine = 1.353. (Call chlorine 60.)

$$\frac{60}{1.353} = 44.35$$

Multiply each of the quotients by this number; we get at once (neglecting trivial discrepancies): N = 20; H = 80; Pt = 10; Cl = 60. Divide through by ten, and put the ammonium radical together, we get $(NH_4)_2PtCl_6$.

Example (2).—Cane sugar. Analysis:

Carbon	42.11 per cent.
Hydrogen	6.43 per cent.
Oxygen	51.46 per cent.
	100.00 per cent.

Quotients: C = 3.51; H = 6.43; O = 3.215. We see that the H is twice as large as the O. Remains only to get simple ratio between C and O. (Call the carbon 60.)

$$\frac{60}{3.51} = 17.1$$

Hence 60 : 55 = 12 : 11. Formula becomes then $C_{12}H_{22}O_{11}$.

It has also been suggested to throw the two numbers into a "continued" fraction, selecting the "convergent" which seems most reasonable.

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Problem IV.—(*b*) Experimental data as aids to determination of formula.

Many physical and chemical data may be obtained which, though they will not change the *relative* number of atoms as given by the above method, may indicate what *multiple* of the provisional numbers must be taken to satisfy the facts.

Later the subject of vapor density will be taken up, and some mention will be made of the methods which deduce molecular weight from considerations of boiling point, freezing point (of solutions), and finally of vapor tension. These, however, are not strictly chemical. Another method remains, which we now explain and illustrate in a single example.

This method consists in the substitution in the compound under discussion of a fraction of one of its constituents.

Take acetic acid. Its provisional formula would be found to be CH_2O. That is, this is the simplest possible expression of the *relative* numbers of C, H, and O atoms.

But it is found that one *fourth* of the hydrogen can be replaced by silver, and that the simplest formula obtainable for silver acetate is: $AgC_2H_3O_2$. Also, chlorine may be substituted for one, two or three-fourths of the hydrogen. The conclusion is inevitable that there are not less than *four* atoms of hydrogen in the original body, hence we multiply the provisional formula by two, obtaining as the probable true formula the expression: $C_2H_4O_2$.

EXCESS AND DEFICIENCY.

Problem V.—Given actual weights of certain elements or compounds, whose chemical relations are known, find which of the two is in chemical excess over the other, and by what weight or proportion.

This finds its application both in manufacturing chemistry and in metallurgy—in the latter, both in furnace work and wet processes (*e.g.*, chlorination and cyaniding).

The problem is at once recognized as the same in principle as those in which we are required to find weights which shall be *chemically* equivalent to certain other weights, of different substances. The only way to ascertain what is the excess or deficiency of a given element is to carry out the same principle, and compare the weights thus obtained. The "excess" is then

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ascertained by the somewhat obvious method of subtracting one from the other.

Some of the illustrations are metallurgical, others more general.

Examples.—(*a*) We find in an ore SiO_2, 40 per cent.; Al_2O_3, 20 per cent. We are calculating on a "singulo" basis, which here indicates $(Al_2O_3)_2(SiO_2)_3$. What is the percentage of silica in excess of the formula?*

A rough computation is often made to determine which of the elements is in excess. In the present case the question has already indicated that it is the silica.

We make the usual proportion. Find by this means the chemical requirement of either silica or alumina, using the given percentages just as though they were actual weights.† Begin, then, with the alumina, and use "approximate" atomic weights.

$2Al_2O_3 : 3SiO_2$ = lbs. alumina : lbs. SiO_2 required
204 : 180 = 20 : 17.64

Silica in the ore 40 per cent. Required, 17.64 per cent. Excess, 40 − 17.64 = 22.36 per cent.

(*b*) Taking the results of the last problem as a basis, what weight of pure limestone $CaCO_3$, (CaO = 56) would satisfy the silica excess on singulo formula, *i.e.*, 2CaO, SiO_2?

(Note.—To calculate for 2CaO we must figure from $2CaCO_3$.)

$SiO_2 : 2CaCO_3$ = SiO_2 excess : Req. limestone.
60 : 200 = 22.36 : 74.53. *Answer.*

Proof: The 74.53 lbs. limestone yield 41.74 lbs. CaO. (Problem III.) 41.74 lbs. limestone require 22.36 lbs. silica, on the given formula, that is, the exact excess as previously computed. (Operations omitted.)

Other illustrations of "excess" problems in slag calculations are given in the second part. We here annex a few general cases.

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* Explanations of the terms "singulo," etc., in slag problems, will be found in the second part, under calculations referring chiefly to furnace charges.

† In the metallurgical part we assume the standard weight, in figuring, of 100 lbs. This makes lbs. and percentages into identical figures, and often prevents error or confusion.

Evidently we can figure as above in percentage, and, if necessary, translate into "actual weights" afterwards.

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(*c*) Add one gram CaO to one gram H_2SO_4. (1) Which is in excess? (2) How much $CaSO_4$ formed? (3) How much left over of the substance which is in excess?

Ans. (1) CaO. (2) 1.38+ grams. (3) 0.4286 CaO excess.

(*d*) One lb. of iron is dissolved in two lbs. of sulphuric acid. What weight of iron will it still dissolve?

$$Fe + H_2SO_4 = FeSO_4 + H_2$$

Ans. 0.1428 lb. iron.

(*e*) One lb. of iron and one lb. of sulphuric acid. How much iron remains unacted on? *Ans.* 0.4286 lb.

(*f*) 10 lbs. H_2SO_4 dissolves 3 lbs. iron. How many lbs. of zinc will it now dissolve? *Ans.* 3.15.

(*g*) A mineral analyzes:

SiO_2	41.6 per cent. (Si = 28)
$CaCO_3$	50.0 per cent. (Ca = 40)
$MgCO_3$	8.4 per cent. (Mg = 24)

After combining with the lime and magnesia according to the formulæ, $CaSiO_3$ and $MgSiO_3$, what percentage of silica will remain in excess? *Ans.* 5.6 per cent.

(*h*) 9.8 grams H_2SO_4 precipitate 23.3 $BaSO_4$ from a solution of $BaCl_2$. The solution still contains 20.8 $BaCl_2$. What was deficit in the H_2SO_4 added? *Ans.* 9.8 grams.

(*i*) One lb. of zinc, one of iron and one of lime (CaO), are dissolved in ten lbs. of sulphuric acid. How much of the latter remains free? *Ans.* 4.99 lbs.

Use approximate weights in all of the above problems. Other examples of excess and deficiency will be found later. They involve gas volumes, hence can hardly be logically inserted before that topic has been treated.

ATOMIC AND MOLECULAR WEIGHTS.*

Problem VI.—Given the analysis of a compound in which the atomic weight of one element is unknown, to determine the "weight" of that one.

All the variants of this problem include analytical data in

* Problems under this heading which involve "gas volumes" should be omitted until that subject has been mastered. It has been found impossible to maintain an absolutely "logical" sequence in every detail.

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some form. The student should realize that such data *taken by themselves* do not always furnish the means for solution of the problem.

Theoretical chemistry is no part of this manual, but some explanation is demanded of the data needed to establish atomic weights. This is a mere outline to enable the student to perceive the limitations of analysis *alone* in the general solution of these problems.

The reader is supposed to be acquainted with the usual definitions of "atom" and "molecule," and to understand "Avogadro's rule."

The compound called "marsh-gas" is to be analyzed. The combining weight of hydrogen is here assumed as unity.

The analysis will show carbon 75 per cent., hydrogen 25 per cent.

Were this all, we might reasonably call the combining weight of carbon three, having assumed that of hydrogen as one. For the actual weight of the carbon is three times that of the hydrogen.

$$\frac{75}{25} = 3$$

We next analyze olefiant gas, finding carbon 85.71, hydrogen 14.29.

$$\frac{85.71}{14.29} = 6$$

Since, then, we have exactly *six* times as much carbon as hydrogen, the evidence for at. wt. of carbon = 6 seems to be as good as for 3.

Acetylene gas, again, gives the composition, carbon 92.31, hydrogen 7.69. Twelve times as much carbon as hydrogen.

$$\frac{92.31}{7.69} = 12$$

Dropping the special illustration, it is seen at once that analysis of itself may be quite inadequate to answer the question of atomic weight, or, as called above, "combining" weights.

If the atomic theory be admitted, then the "atomic weights" are the relative weights of the atoms. Here it may be well to remind the student that we regard an "atom" as the smallest particle whose chemical action we recognize, and warn him to throw

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aside all objections, whether ignorant or merely pedantic, which are founded upon the Greek words from which "atom" is derived.

Considerations which bear upon the determination of atomic weights, aside from proportions by weight (analysis), are in part:

(1) Variant proportions between two elements in a series of compounds containing those elements only. (Law of multiple proportions.)

(2) Substitution of one element for another, wholly or in part, in a compound.

(3) Vapor Density, if the compound can be obtained as a gas.

(4) Specific heat of the element under investigation.

(5) Place of the element in the periodic system.

Several of these will receive attention in the course of the presentation of problems. Full discussion of them is out of place in a manual chiefly devoted to arithmetical computation.

In many of the problems the formula is assumed to begin with, in which case the calculation of the atomic weight of one element becomes a mere matter of "proportion." Every instructor in chemistry knows how difficult it is to prevent students from "taking for granted" what they see in print. Hence, although the determination of atomic weights is work only for an advanced specialist, it is thought important to place the limitations of the purely analytical method clearly before the mind of the reader.

The more advanced student is warned, however, that it is the conclusions and not the philosophy of theory that we present.

Atomic weights being purely relative, we must have some basis of comparison, and this must be found in some one of the elements themselves.

Were the ratio of oxygen to hydrogen exactly sixteen to one, as was so long assumed, we should doubtless to-day use hydrogen as unity in this scale of relative weights.

Various reasons, however, urge the use of oxygen taken as sixteen, as the basis. The arguments which have finally prevailed in this usage do not belong here.

In some solutions relating to atomic weights, and in many cognate problems, we have shown complete operations, in others we have simply given the answers, while in a few cases we have partly indicated the method, leaving something to the device of the student.

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VAPOR DENSITIES OF ELEMENTS AND COMPOUNDS.

The atomic weights of certain elements being known, it does not follow that we can immediately announce the molecular weight of a compound of such elements, even when we have the analysis of the compound. Under the head of calculations of gas volumes will be found the general laws regulating the relation of molecular weights as deduced from the density of compound substances, when in the gaseous condition.

It is probable that certain elements have different molecular weights under different conditions. It is hardly credible that the two conditions of phosphorus, "white" and "red," have the same molecular weight; the same may be said of the three conditions of carbon. Oxygen and sulphur have also been cited as probable cases of variation. On the other hand, these differences may vanish under high temperatures, and it is difficult to see how they can be proved by physical experiment.

Hydrogen, oxygen, nitrogen, chlorine (below 800° C.), bromine, iodine, sulphur (above 1000° C.), selenium, tellurium and potassium have vapor densities such that, *taking density of hydrogen* = 1, the numbers correspond with respective atomic weights. Their "double densities" (O_2 = 32, etc.) are double their atomic weights, and *probably* express their molecular weights. These molecules would then contain each two atoms. Density of mercury and cadmium as vapor is half atomic weight (when D. of hydrogen = 1). The inference is that their atomic and molecular weights are equal.

Densities of the vapors of arsenic and phosphorus are twice their atomic weights, taking the same unit of comparison, we infer that their molecules are respectively As_4 and P_4.

As to the molecular weight of compounds, if we assume the "Avogadro" rule the density gives us the molecular weight at once. There are many compounds which cannot be vaporized, and their molecular weights, so far as present means of determination go, remain unknown.

It follows, that the formulæ by which we express these compounds may be nothing more than the true formula reduced to its *simplest arithmetical ratio of elements*. We have, for example, no means of proving that ferrous sulphate, which we write

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$FeSO_4$, may not have a much more complex constitution than indicated by this formula.

Acetylene gas and benzene have absolutely the same analysis. But the densities are 26 and 78 respectively ($H_2 = 2$). The analyses show that the ratio of carbon to hydrogen by weight is as 12 : 1, hence we write the molecule of the first one as C_2H_2 and of the latter as C_6H_6.

We cannot entirely pass over the phenomenon of substitution, as affecting the determination of structure or at least molecular weight, but its full consideration belongs to general chemistry.

Take, then, the case of methane, CH_4. It can be so treated that one-fourth, never less, of its hydrogen can be replaced by chlorine. Also, two-fourths, three-fourths and all four-fourths can be replaced, and in each case the weight of the displaced hydrogen is to the weight of the substituted chlorine as 1 : 35.5. Unless we are to throw aside the atomic theory entirely, we must conclude that each of these replacements is of one atom of hydrogen by one of chlorine. This, then, forms another and often a very important method of securing evidence as to the probable number of atoms in a molecule, and may serve to correct the "empirical" formula derived from analysis alone.

Examples.—(*a*) Glucinum has now attributed to it the atomic weight of 9.1 and its oxide has the formula GlO. Formerly its oxide was written Be_2O_3. As this threw it out of line in the Periodic System, experiments on its specific heat showed its formula to be as now adopted.

The composition of the oxide is: Gl, 36.25 per cent.; O, 63.75 per cent. What would be the atomic weight under the older formula?

Solution.—This and all other problems of its kind may be best stated under the form of a simple proportion.

$$O_2 : Gl_2 = O_2 : 2x$$
$$63.75 : 36.25 = 48 : 27.29 \qquad x = 13.64$$

(*b*)* A gas analyzes:

Carbon	92.31 per cent.
Hydrogen	7.69 per cent.
Total	100.00 per cent.

* These and other problems marked with * should be omitted as already indicated, until section on "gas volumes" has been mastered.

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One liter of this gas weighs 3.4821 grams. Find its molecular weight and formula.

$$x : 22.4 = 3.4821 : 1$$
$$x = \text{molecular weight} = 78$$

From the analysis we have:

$$92.31 : 7.69 = 12 : 1$$

Hence the atoms are present in the ratio 1 : 1. Dividing 78 by 13* we get quotient of 6, hence formula may be assumed as C_6H_6.

(*c*) A gas analyzes the same as in (*b*) but a liter of it weighs 1.1607 grams. Find molecular weight and formula.

Solution.—The same proportion indicates molecular weight as 26. Dividing as before by 13 (12 + 1) we get 2. Formula C_2H_2. These, although not problems for the finding of atomic weights, serve to illustrate a very closely related topic.

(*d*) Specific heat of copper is 0.0952.

An oxide of copper analyzes:

Copper	88.83 per cent.
Oxygen	11.17 per cent.
	100.00 per cent.

What is the atomic weight of copper?

The proportion gives us:

$$11.17 : 88.83 = 16 : x$$

According to this analysis, with no limiting data, we should conclude that the atomic weight of copper might well be 127.2, that being the value of x.

Following the law of Dulong and Petit, this number, multiplied by the specific heat, should give a product of about 6. However, $127.2 \times 0.0952 = 12.1+$ or fully double the average "atomic heat." This indicates that we should divide our result by two, assigning the metal an atomic weight of 63.6, with formula for this oxide Cu_2O. This is confirmed by the analysis of cupric oxide (CuO), and by various other data.

* *I.e.*, C(12) + H(1).

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(*e*) MCl_2 weighs "*a*." MBr_2 weighs "*b*." What is the atomic weight of M? (Cl = 35.5. Br = 80.)

Answer. $$\frac{160a - 71b}{b - a}$$

The student should work out the "why" of this formula. See next problem.

(*f*) MCl_2 weighs 3.78 grams. MBr_2 = 6.45 grams. Find atomic weight of M. Note that the formula, *i.e.*, valence of M, is assumed in these cases.

Here $a = 3.78$; $b = 6.45$. $b - a = 2.67$, etc.

M works out very easily to 55.

The method being quite general may be applied to any similar case.

(*g*) A metal is acted on by nitric acid, supposed equation being:

$$3M + 8HNO_3 = 3M(NO_3)_2 + 4H_2O + 2NO$$

(This equation is intended merely for an exhibit of relation of metal to product. Relation of nitric acid to dissolved metals is highly irregular.)

Weight of "M" = 1 gram, nitrate = 2 grams. Find atomic weight of "M." *Ans.* 124.

(*h*)* A metal "X" acts on water. $2X + 2H_2O = 2XOH + H_2$

Weight of "X" used = 10 grams. Hydrogen evolved = 4.8692 liters. Find atomic weight of "X."

$$X_2 : 22.4 = 10 : 4.8692. \qquad X_2 = 46. \quad X = 23.$$

(*i*)* A gram of metal is dissolved in acid, liberating 930 c.c. (at 18° C. and 750 mm.) of hydrogen. Find atomic weight of "M," assuming equation:

$$M_2 + H_2SO_4 = M_2SO_4 + H_2$$

Form of solution. Call the volume of the gas reduced to "normal" conditions "*V*," then we have:

$$V : 1 = 22.4 : x \left(\text{atomic weight} = \frac{x}{2}\right)^*$$

(*j*) One gram of silica (SiO_2) is derived from 2.8179 grams silicon tetrachloride ($SiCl_4$). Find atomic weight of silicon. (Cl = 35.45.)

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Solution. 2.8179 − 1 = 1.8179; this represents excess of Cl_4 over O_2. The theoretical side is, Cl_4 = 141.8 and O_2 = 32. Difference = 109.8. Hence:

Diff. in mol. wts.	:	mol. wt. of O_2	=	Diff. in wt.	:	wt. of O_2
109.8	:	32	=	1.8179	=	0.5298

SiO_2 weighed 1 gram, silicon weighs 1 − 0.5298 = 0.4702.

Finally,

$$O_2 : Si = O_2 : Si$$
$$5298 : 4702 = 32 : 28.4$$

Atomic weight of silicon = 28.4.

(Carefully note use of the *difference* between atomic weights for a datum.)

(*k*) $$AgBr + Cl = AgCl + Br$$

This equation represents displacement of bromine by chlorine.

Suppose atomic weight of bromine to be unknown. We have the following data. Weight of silver bromide 1.6910. Weight of silver chloride 1.2904. (Loss of weight in the replacement, 0.4006.) Find the atomic weight of bromine.

Composition of AgCl being known, we find weights of silver and chlorine to be, respectively, 0.9714 and 0.3190. Subtracting weight of silver from weight of silver bromide: 1.6910 − 0.9714 = 0.7196 = weight of bromine.

Nothing remains except to put the two weights into proportion with their atomic weights, that of bromine being the unknown term.

Weight of chlorine	:	weight of bromine	=	at. wt. Cl	=	at. wt. Br
3190	:	7196	=	35.45	=	79.97

The above problem might also be solved by using the difference in atomic weight as in (*j*), just above. Thus we have a loss of 0.4006 and this is obviously the *excess of weight of bromine above chlorine.* This difference is wholly due to the excess of the atomic weight of bromine over that of chlorine, it being evident that the difference in actual weights must be proportional to the difference in atomic weights. We know the weight of the chlorine(0.319) and the atomic weight of chlorine (35.45). Now call the atomic weight of bromine "*x*," we have:

$$x - 35.45 : 35.45 = 0.4006 : 0.319$$

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That is, the *difference* in atomic weights is to the atomic weight of chlorine, as the *actual loss* of weight is to the actual weight of chlorine.

The result is the same as by the more direct method.

(*l*)
$$\begin{aligned} RO + 2HCl &= RCl_2 + H_2O \\ FeS + H_2SO_4 &= FeSO_4 + H_2S \\ RCl_2 + H_2S &= RS + 2HCl \end{aligned}$$

In the above equations, RO and FeS weigh each one gram. The equations are all "in chain," *i.e.*, the H_2S from one gram of FeS just precipitates RS from the original one gram of RO.

Use "approximate" atomic weights, *i.e.*, Fe = 56, etc. Deduce atomic weight of R without the use of equation or proportion.

Solution.—The molecular weights of RO and FeS must be equal. But since the molecular weight of FeS is 88 that of RO must also be 88.

Then RO − O = R. That is, 88 − 16 = 72 = atomic weight of R.

(*m*) Eleven grams of a sulphide RS when oxidized to RSO_4 now weigh nineteen grams. Find the atomic weight of R. (S = 32.)

Solution.—The oxygen weighs 8 grams. Hence the sulphur weighs 4 grams. This leaves 7 grams for the weight of the "R."

Or
$$8 : 64 = 7 : 56$$
$$\text{At. wt. of R} = 56$$

(*n*) One gram of phosphorus produces 2.2903 grams P_2O_5. What is the atomic weight of phosphorus?

Solution. 2.2903 − 1. = 1.2903 = weight of oxygen.

Molecular weight of five atoms of oxygen = 5 × 16 = 80.

$$1.29 : 1 = 80 : x \qquad x = 62$$
$$\frac{x}{2} = \text{at. wt. of phosphorus} = 31$$

(*o*)*
$$\begin{aligned} RS + 2O_2 &= RSO_4 \\ RSO_4 + BaCl_2 &= RCl_2 + BaSO_4 \\ RCl_2 + 2AgNO_3 &= 2AgCl + R(NO_3)_2 \\ R(NO_3)_2 \text{ (ignited)} &= RO + N_2O_5 \\ RO + H_2 &= R + H_2O \end{aligned}$$

The metal "R" from the last reaction weighs 1.815. The $BaSO_4$ weighs 7.7042.

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Find (1) atomic weight of "R;" (2) weight of RS; (3) weight of RO; (4) weight of AgCl; (5) volume of hydrogen gas; (6) volume of oxygen gas.

Answers. (1) 55; (2) 2.873; (3) 2.343; (4) 9.4631; (5) 0.7392 liter; (6) 1.4784 liters.

(*p*) $KClO_3 = KCl + O_3$. Having assumed this equation let us suppose atomic weights of potassium and chlorine to be unknown, but that of silver to be known (say 108). Call weight of $KClO_3$ "*a*." Loss on ignition (O_3) = "*b*." The chlorine in the residue is precipitated as AgCl whose weight is "*c* + *d*." Silver is now separated and weighed as metallic silver "*d*," leaving weight of chlorine as "*c*."

Required the atomic weights of chlorine and potassium.

Since "atomic and actual weights are in equal ratio" we have:

$$d : c = 108 : x \qquad x = \frac{108c}{d} = \text{at. wt. chlorine}$$

We have also the actual weight of the potassium, viz: $a-b-c$.

If then the atomic weight of the potassium be called "*y*" we have:

$$b : a - b - c = 48 : y \qquad y = 48\frac{(a - b - c)}{b}$$

(*q*) *A dyad metal "R" is dissolved in acid:

$$R + H_2SO_4 = RSO_4 + H_2$$

Weight of the metal, one gram. Volume of the hydrogen, 0.3425 liter.

Find atomic weight of "R." *Ans.* 65.4.

(*r*) *Vapor of phosphorus oxychloride weighs 6.8529 grams per liter. What is the molecular weight? *Ans.* 153.5.

(*s*) MnS contains 36.83 per cent. sulphur. What is atomic weight of manganese?

$$36.83 : 63.17 = 32.06 : 55$$

(*t*) One gram of a dyad metal is dissolved and precipitated as RS. The sulphur in this is determined as $BaSO_4$ whose weight is 2.3346 grams.

What is the atomic weight of the metal? *Ans.* 100.

(*u*) One gram of $R(NO_3)_2$ ignited, leaves 0.45 gram RO. What is atomic weight of "R."

$$R + 16 : R + 124 = 0.45 : 1.00 \qquad R = 72.36$$

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(*v*) 2RO is converted into R_2X without change of weight. What is the atomic weight of "X"?

Ans. Twice that of oxygen.

(*w*) From one gram of "R" is derived 0.9614 $R_2P_2O_7$. Find atomic weight of R. *Ans.* 137.

(*x*) One gram of RSO_4 is converted into $R_2P_2O_7$, which is not weighed, but is converted into $Mg_2P_2O_7$ which weighs 0.6895 gram. What is the atomic weight of R? (Use "approximate" weights, Mg = 24, etc.) *Ans.* 65.

(*y*) Oxide M_2O of a monad metal being converted into bromide goes from 75 grams to 435 grams. What is atomic weight?

Ans. 7.

(*z*) MCl = 8.2016. AgCl = 15.7707. At. wt. of M = 39+

RAOULT'S LAW.

"One molecule of a compound dissolved in 100 molecules of a liquid lowers the freezing point of the liquid by 0.62° Centigrade."

The figure 0.62° is nearly, but not quite a constant for all cases. The limitations of this law are very great, and it may be said without going into any general discussion, that it does not apply to aqueous solutions of inorganic salts.

If P = weight of the substance dissolved and L = weight of solvent.

M = molecular weight of solvent and m = molecular weight of substance dissolved.

E = reduction in freezing point, in degrees Centigrade, then:

$$\frac{P}{L} : \frac{m}{100\,M} = E : 0.62°$$

or, translating the formula, we see that by comparing the *observed* reduction in temperature (E), with the constant 0.62°, we deduce ratio between numbers of molecules. Since we are supposed to know the molecular weight of the solvent (M) and since all the other numbers are data of the experiment, we solve for m:

$$m = \frac{P \times 62 \times M}{L \times E}$$

Examples.—(*a*) To 780 grams benzene (C_6H_6, molecular weight = 78) add 124.6 grams anthracene (established formula is $C_{14}H_{10}$).

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Observed depression of temperature on freezing = 4.34° C.

$$P = 124.6,\ L = 780,\ M = 78,\ E = 4.34$$

$$m = \frac{124.6 \times 62 \times 78}{780 \times 4.34} = 178.$$

Analysis of anthracene is C, 94.38; H, 5.62. Empirical formula easily deduced as C_7H_5, molecular weight as 89, corrected by above to $C_{14}H_{10}$ molecular weight = 178 = 89 × 2.

MOLECULAR WEIGHTS DETERMINED FROM FREEZING AND BOILING POINTS OF SOLUTIONS.

Raoult's rule is defective in that it assumes a constant depression of freezing point for various solvents. It is retained, however, though no further examples are given under it.

The following rules for determination of molecular weights of a certain class of substances apply both to depression of freezing point and raising of boiling point. As the "constant" in these cases varies for each solvent, a table is appended of the values of the constant for a few of the more important solvents.

(*A*) *From depression of freezing point.*

If the solution of w grams of a substance in 100 grams of a liquid lowers freezing point $T°$, then molecular weight will equal

$$\frac{K \times w}{T}$$

In this formula K is a constant differing for each liquid.

Example.—Constant for benzene being 50, solution of 2 grams of nitrobenzene in 100 grams benzene lowered freezing point by 0.8 Centigrade.

$$K = 50.\quad w = 2.\quad T = 0.8.\quad \text{Mol. wt.} = \frac{50 \times 2}{0.8} = 125$$

Nitrobenzene has the formula $C_6H_5NO_2$ according to usual statement. This would give 123 as molecular weight. Since the question in regard to molecular weight is usually whether a certain trial number deduced from analysis, *or a multiple of same* is the true figure, the approximation 125 settles the determination in favor of the formula as given.

Analysis would in this case evidently give us 123 as lowest possible figure, since nitrogen appears to the extent of but one atom. In the case under Raoult's rule, the "empirical" figure is doubled.

(*B*) *From raising of boiling point.*

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If the solution of w grams of a substance in 100 grams of a liquid raises boiling point $t°$ C, then molecular weight $=$

$$\frac{L \times w}{t}$$

In this formula, "L" is a constant differing for each liquid, like "K" in the freezing case.

Example.—Constant for ether being 21.1, solution of 3.533 grams iodine in 100 grams ether, raised boiling point 0.296° Centigrade.

$$L = 21.1. \quad w = 3.533. \quad t = 0.296. \quad \text{mol. wt.} = \frac{3.533 \times 21.1}{0.296} = 252$$

The doubled atomic weight of iodine approximates 254, hence the above determination would lead to the adoption of that figure.

(These rules and the table below are taken with some slight change from Lupton's Chemical Arithmetic, London, 1907. They have little to do with strictly stoichiometric work, and are inserted more as reference matter than for working examples.)

CONSTANTS UNDER ABOVE RULES.

Solvents.	K.	L.
Water	18.5	5.2
Acetic acid	39	25.3
Benzene	50	26.7
Carbon disulphide	....	23.7
Chloroform	....	36.6
Alcohol	....	11.5
Ether	....	21.1
Acetone	....	16.7

COMPUTATION OF GAS VOLUMES.

Gas volumes are most readily computed in the metric system. After setting forth the method, however, based upon the crith as the weight unit and the liter as the volume unit, we shall show how to compute from pounds and cubic feet.

The unit weight assumed for gas calculations is the "*crith*" which represents the weight of one liter of hydrogen gas under normal conditions of temperature and pressure, viz: 0° C., and 760 mm. barometer.

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Expressed in grams this weight is 0.089873. Since the adoption of oxygen as 16, it has been suggested that a crith based upon a hypothetical gas one-sixteenth of the density of oxygen would be the proper unit.

The weight of one liter of oxygen is 1.42961 in grams. One sixteenth of this is 0.08935. The purpose of this work, however, not being to discuss refinements of scientific precision, we shall adopt the approximate figure of 0.09 gram—nine-hundredths of a gram.

Dividing unity by this figure we get 11.11 as the number of criths in one gram. Hence:

To convert grams into criths, multiply by 11.11 *or divide by* 0.09.

To convert criths into grams, multiply by 0.09 *or divide by* 11.11.

The calculations will be slightly in error, because our "crith" is too heavy. Practically this is of no moment whatever. In any operation, whether for lecture demonstration or manufacturing process, the error is so slight that the average "shortage" of product as compared with theory will far exceed it.

The first thing for the student to remember in the symbolism for gases, is that equal numbers of molecules* occupy equal volumes (Avogadro's rule). Just as the symbols for elements do not indicate the atomic weights, but carry them "understood," so the symbolism for gases indicates their relative *volumes* only in the light of the "rule" of Avogadro. *Equal numbers of symbolic molecules indicate equal volumes.*

Take the following gas formulæ:

$$H_2 : HCl : NH_3 : CH_4 : PF_5 : CO : CO_2 : COCl_2 : C_2H_4 : CH_3Cl$$

Each of these expressions indicates one molecule. *The volumes of all the expressions are equal.*† This volume relation is just as fully borne out in actual operations, involving actual volumes, as are the weight relations we have hitherto discussed. A coefficient multiples the volume just as it does the weight. *We shall call the molecular expression two volumes.*

If the expression for the element alone, O for example, indicates one volume, then any expression of a molecule indicates two volumes. It is true that it is theoretically incorrect to

* We are little concerned as to whether this is or is not the true theoretical interpretation of the facts. Since it is a "working hypothesis" and does not lead us astray in stoichiometric work, it amply serves our purpose.

† *I.e.*, if the expressions occur in the same equation or in related equations.

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write a single symbol in a great majority of cases. But in numberless cases they will continue to be so written by persons who are in a hurry, and have not the fear of the theorist before their eyes. For these the " two-volume " convention is best adapted.

The "density" of a gas we shall consider as expressed by the same figure as its molecular weight. (Oxygen = 32, hydrogen = 2.016, CO = 28, etc.)

As there are thousands of persons who have learned that the "density" of a gas is *one-half* of its molecular weight, it may be well to point out here that the whole matter is purely conventional. Any set of numbers might serve as expressions for density so long as they were in the proper *ratios* expressing the experimental facts.

While hydrogen was accepted as "unity," there was no small convenience in taking its density as unity and comparing all other densities on that basis. However, the convention of (practically) doubling the old densities has obtained almost universal acceptance, presenting the advantage of giving one set of numbers instead of two. The anomaly of a scale of comparison without any "unit" (*i.e.*, numerical unit) does not make any difficulty. We have no numerical unity any longer in the table of atomic weights, since we base everything on O = 16.

Together with the adoption of the molecular weight figures as expressions for density, came also in some texts the usage of calling the molecular volume "one" (type) volume. Here again all is mere convention. Nevertheless, there is great convenience sometimes in conventions, and as there is no practical reason to prevent us from calling the molecular volume "two" instead of one, and as the "two-volume" convention seems to the author to greatly facilitate comprehension of the subject in presentation to beginners, we retain it, albeit it is of little consequence whether we do or not in a text of this kind.

However, it seems easier to remember that one volume of nitrogen and three of hydrogen combine to make *two* of ammonia than that one-half a volume of the first and one and a half of the second combine to form *one* volume. All fractions disappear under the two-volume idea, whether in combination or in decomposition. Nor can the author see any force in the criticism that there is "inconsistency" between this convention and the adoption of the molecular weight figure for density.

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We call the molecular expression, then, *two* type volumes, as already set forth. Let us now translate an equation into volumetric relations:

$$C_2Ca + 2H_2O = Ca(OH)_2 + C_2H_2$$

Acetylene from "carbide." Assume concrete volumes, viz: 1 vol. = 1 liter. Put the equation into criths, as to weight, or into liters as to volume, the results are the same. The molecular weight of the gas is 26; there will be 26 criths of it, and 2 liters of the gas. But since we have a concrete weight for one term all the others follow (problems I and II). We shall have 64 criths of the carbide, 36 criths of water.

Compare now the relation of the weight of the carbide to the volume of the acetylene. On the theoretical side we note that (in this particular case) one molecule of the first gives two "type volumes" of the second. Taking actual weight of the one and actual volume of the other, we see that relation of molecular weight to number of type volumes is the same as the relation of crith weight to liter volumes.

In this illustration we have made actual and theoretical figures coincide. The student is recommended to "invent" other cases, and prove that the application is quite general.

Although we prefer the "22.4" method to be later introduced, we have given precedence to the "crith" as the older method of solution of problems of this nature, and proceed to put it into a formal "rule" with examples.

Deduction of Gas Volumes from Equations Expressing Weights.

Problem VII.—(*a*) Given the equation for the production of a gas, and the weight of any one of the solid compounds entering the reaction, to deduce the volume of the gas. Weights given in grams.

(We call the solid, or liquid, substance the "first" and the gas the "second.")

Following the illustration already given we have the rule:

AS the molecular weight of the first
IS TO the type-volume of the second;
SO IS the weight in criths of the first
TO the volume in liters of the second.

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It is not necessary that the known quantity should be the solid by weight. It is quite the same problem if we assume the volume of the gas and seek the weight of the compound or element which we are to use in its production.

Examples.—(*a*)

$$KClO_3 = KCl + O_3 \text{ (type volumes = 3)}$$

We take 100 grams of potassium chlorate, how many liters of oxygen shall we obtain? (100 grams = 1111 criths.)

Molecular weight of $KClO_3$ = 122.5. Place "abstract" numbers in first member, as usual; that is, the "molecular" weight and the "type" volumes.

$$122.5 : 3 = 1111 : x. \qquad x = 27.2 \text{ (liters of oxygen)}$$

(*b*) $NH_4Cl + KOH = KCl + H_2O + NH_3$ (type volumes = 2)

Required, four liters of ammonia gas, what weight of ammonium chloride?

$$53.5 : 2 = x : 4 \quad (NH_4Cl = 14 + 4 + 35.5 = 53.5)$$
$$x = 107 \text{ criths.} \qquad 107 \times .09 = 9.63 = \text{Answer in grams.}$$

(*c*) $NaCl + H_2SO_4 = NaHSO_4 + HCl$ (2 type volumes)

Given twelve grams of common salt (NaCl), how many liters of hydrochloric acid gas (HCl)?

$$\text{Molecular weight of NaCl} = 58.5. \qquad 12 \text{ grams} = 133.33 \text{ criths}$$
$$58.5 : 2 = 133.33 : x. \qquad x = 4.558 \text{ (liters of HCl)}$$

(*d*) $NH_4NO_3 = N_2O + 2H_2O$ (2 type vols. of N_2O, 4 of H_2O)

Given three liters of N_2O gas, what weight was taken of ammonium nitrate?

$$(\text{Molecular weight of } NH_4NO_3 = 14 + 4 + 14 + 48 = 80)$$
$$80 : 2 = x : 3. \qquad x = 120 \text{ criths} = 10.8 \text{ grams}$$

If it be required to figure cubic feet of gas, *given* weights in pounds, this can be readily done by suitable transformation of the above rule.*

One pound contains 5040 criths. If, then, we raise the criths of the rule to pounds, we must also multiply the liters by 5040.

* A very simple method of using ounces and cubic feet will be found at the close of this chapter.

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However, as we want cubic feet, we must divide this number by 28.32 the number of liters in one cubic foot. The quotient is (very closely) one hundred and seventy-eight.

This forms a new kind of "unit of gas volume." To show exactly what it means we may put it thus:

"A crith has the same relation to a liter as a pound has to 178 cubic feet." Or, better, "A crith is to a pound as a liter is to 178 cubic feet."

It may be convenient to name this volume of gas. Let us call it a "pound-volume," 178 cubic feet.

Now the rule becomes:

"As the molecular weight of the first is to the type volume of the second, so is the weight in pounds of the first to the volume in *pound-volumes* of the second." (We then multiply number of "pound-volumes" by 178 to get cubic feet.)

Examples.—(*a*)

$$CaOCl_2 + H_2SO_4 = CaSO_4,H_2O + Cl_2 \text{ (2 type volumes)}$$

Take 100 lbs. of bleaching powder and find volume of chlorine gas.

(Molecular weight of $CaOCl_2 = 40 + 16 + 71 = 127$.)

$127 : 2 = 100 : x.$ $x = 1.574$ (pound-volumes)

$1.574 \times 178 = 280+$ Answer, 280 cubic feet

(*b*) We are to inflate a balloon with fifty thousand cubic feet of hydrogen gas.

$$Zn + H_2SO_4 = ZnSO_4 + H_2 \text{ (2 type volumes)}$$

How many pounds of zinc must be used? (Atomic weight of Zn = 65.)

First, divide 50,000 by 178, giving the number of "pound-volumes."

$50{,}000 \div 178 = 280.9$. The usual proportion follows:

$65 : 2 = x : 280.9$ $x = 9129$ (pounds of zinc)

In the above problems on gas volumes it is tacitly assumed that the volumes are taken under the "normal" conditions, viz: 0° C. for temperature and 760 mm. barometer. Students are often perplexed by having questions put to them involving at once the chemical and physical conditions. This is all right at the last, but it is better to master principles separately and unite their calculation afterward.

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All conditions being given, viz: chemical equation, temperature and barometer, the computation of volume as above comes first. Then follow the corrections for thermometer and barometer, one after the other.

The "22.4" Method.

A method of calculating gas volumes in relation to weight without the use of the "crith," is found in the fact that the molecular weight* of any gas *taken in grams* occupies twenty-two and four-tenths (22.4) liters. Using this figure we obtain results somewhat more accurate than with our crith of 0.09 gram. The latter, being too heavy, will give weights too high and volumes too low, though not by any serious amount.

The "22.4" liter figure is derived from the weight of 1.4296 grams for one liter of oxygen. It is amply close for any practical application. In using it we do not have to transform grams into criths or the reverse.

Each method has its advantages. The crith has perhaps been more used, but it is hard to see why it should be considered better or easier than the "two volume" to be now explained.

Let us take an actual gas for the explanation. CO_2 has the molecular weight of 44. *Then 44 grams of it will occupy 22.4 liters.*

Calculate this by the approximate "crith" of 0.09 gram. One liter of CO_2 weighs 22 criths. $22.4 \times 22 = 492.8$ criths.

$492.8 \times 0.09 = 44.35$ grams, instead of 44 grams. That is, the weight comes out a little over, as it must, our "crith" having been taken ("for short") a little too large. It is evident, however, that the error is not material in any ordinary case.

We call the expression for one molecule of gas "two volumes," *i.e.*, as before, two "type" volumes. We may now easily construct a rule for ascertaining gas volumes from weights. Let us assume the equation:

$$NaCl + H_2SO_4 = NaHSO_4 + HCl$$

If, in this equation, the *units of atomic weight were grams*, we should have 58.5 grams of NaCl and 22.4 *liters* of HCl.

---

* The student's attention is called to the molecular weights of elementary gases: $H_2 = 2$; $O_2 = 32$, etc. Explanation belongs to theoretical chemistry.

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Take 100 *grams of the salt.* Find the corresponding volume of hydrochloric acid gas. Evidently the proportion must be:

Mol. wt. of NaCl : Mols. × 22.4 of HCl = wt. of salt : x (liters of gas)
58.5 : 1 × 22.4 = 100 : x = 38.29

Problem VII.—(*b*) Equation being given, to find volume of gas directly from gram weights known.

Rule: As molecular weight of first substance
Is to 22.4 times number of molecules of second:
So is weight in grams of first
To volumes in liters of second.

As before, "first" substance means the one whose *weight* is either given or required, "second" substance gas whose *volume* is either given or required. Either can be the unknown. Problems (*b*) and (*d*), below, exemplify the case in which the gas is the known quantity.

The above illustrative problem worked by the "crith"method:

$$58.5 : 2 = 1111 : 37.98 \text{ (liters)}$$

Weight being a trifle too great, volume comes out slightly too small.

For problems of this kind the method seems better than the "crith" way. The latter, however, is too generally used to be omitted.

Examples under the "22.4" method for gas volumes:

(*a*) $CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$

Take 125 grams calcium carbonate, what volume of carbon dioxide gas?

Molecular weight of $CaCO_3$ = 100. Molecules of CO_2 = 1.

$CaCO_3 : CO_2 = CaCO_3 : CO_2$
100 : 1 × 22.4 = 125 : x = 28 liters

5
4) 112.0
28.00

(Substitute 4 and 5 for 100 and 125. Similar simplifications are often possible, and the student should be on the lookout for them.)

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(*b*) Same equation as (*a*), above. We want 100 liters of carbon dioxide, what weight in grams shall we take of calcium carbonate?

$$CaCO_3 : CO_2 = CaCO_3 : CO_2$$
$$100 : 1 \times 22.4 = x : 100$$
$$10{,}000 \div 22.4 = 446.43 = \text{grams of calcium carbonate}$$

(*c*) $MnO_2 + 2NaCl + 2H_2SO_4 = MnSO_4 + Na_2SO_4 + 2H_2O + Cl_2$

(Evolution of chlorine gas from manganese dioxide, common salt and sulphuric acid.)

Take 435 grams of the manganese oxide. What volume of chlorine?

$$MnO_2 : Cl_2 = MnO_2 : Cl_2$$
$$87 : 1 \times 22.4 = 435 : x = 128 \text{ liters.}$$

Note that Cl_2 is *one molecule* of chlorine.

(*d*) $C_2Ca + 2H_2O = Ca(OH)_2 + C_2H_2$

Evolution of acetylene gas by action of water on calcium carbide.

We want 1000 liters of acetylene; how many grams of carbide must we take?

$$C_2Ca : C_2H_2 = C_2Ca : C_2H_2$$
$$64 : 22.4 = x : 1000$$
$$(x = 2857)$$

Let v be the volume in liters, and w the weight in grams of any mass of gas we have the general relation:

$$22.4 : v = \text{m.w.} : w$$

Hence, to find weight of a *given volume* of gas, *multiply volume by molecular weight, and divide by* 22.4.*

To find volume of a *given weight* of gas, *multiply weight by* 22.4* *and divide by molecular weight.*

Examples.—(*a*) Find weight of 49.4 liters of sulphuretted hydrogen gas.

(Molecular weight $2 + 32 = 34$)

$49.4 \times 34 = 1679.6$. $1679.6 \div 22.4 = 75$ grams

(*b*) Find volume of 237.72 grams of chlorine gas.

$237.72 \times 22.4 = 5324.928$. $5324.9 \div 71 = 75$ liters

(Molecular weight of chlorine $= 35.5 \times 2 = 71$)

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* The reciprocal of 22.4 is 0.04464. It can be used as multiplier instead of 22.4 as divisor, and vice versa.

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These measurements are not absolutely accurate, although close. Just as in the laws of volume under variations in heat and pressure, careful observation shows slight discrepancies, so the various gases do not show absolute accord with the "22.4" rule. But the differences are trivial, and for practical applications may be said not to exist.

Conversion of Molecular-gram Method into English Weights and Volumes.

This conversion is easier than with the "crith," because of an accidental relation between gram, ounce, liter and cubic foot.

A liter holds one thousand grams of water. A cubic foot holds one thousand ounces of water (998.4).

We have then the convenient fact that grams and liters are related just as are ounces and cubic feet.*

Thus, substituting ounces for grams, and cubic feet for liters, we may continue to use the number 22.4, with close approximation to exact results.

That is: 22.4 *cubic feet of any gas weighs "M" ounces.*

"M" stands for the molecular weight of the gas considered.

Example.—(*a*) Calcium carbide, 94 per cent. pure, is to generate acetylene gas. Wanted 1000 cubic feet of gas, what weight of carbide must be taken?

Equation is:

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2$$

$$CaC_2 : C_2H_2 = \text{ounces} : \text{cubic feet.}$$

$$64 : 22.4 = x : 1000$$

$$x = 2857 \quad \frac{2857}{0.94} = 3394 \quad \frac{3394}{16} = 212 \text{ lbs.}$$

(*b*) Coal contains 80 per cent. carbon. How many tons of it produce ten million cubic feet CO_2 gas. How many cubic feet of air are consumed in the burning?

The equation of the reaction is:

$$C + O_2 = CO_2$$

$$C : CO_2 = \text{ounces carbon} : \text{cubic feet } CO_2$$

$$12 : 22.4 = x : 10{,}000{,}000$$

* I am unable to state who first pointed out this relation to me. It is given in the "Metallurgical Calculations" of Prof. J. W. Richards, who rediscovered it. It does not seem to be much known.

It is also given in Professor Wells' "Chemical Arithmetic."

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Call oxygen 21 per cent. of the air by volume. Dividing the ounces obtained by 32,000 we get 167.4107 tons carbon, or, dividing by 0.80 (for coal), 209.263 (209 tons and 526 lbs.). The oxygen (O_2) is of same volume as the carbon dioxide (CO_2), hence the air is obtained by dividing that figure by 0.21.

Ans. 47,619,047 cubic feet.
209.263 tons.

(*c*) Ninety thousand cubic feet of hydrogen gas are required by the equation:

$$Fe + H_2SO_4 = FeSO_4 + H_2$$

How many pounds of iron must be taken?

$$56 : 22.4 = x : 90{,}000. \qquad x = 225{,}000$$

This 225,000 being in ounces we divide by 16, getting:

Ans. 14,062 lbs.

(*d*) A blast furnace, in a given time, blows in a million cubic feet of air. How many tons of carbon will this burn to carbon dioxide gas?

$$C + O_2 = CO_2$$

Air contains 21 per cent. by volume of oxygen, so we figure on 210,000 cubic feet of the latter.

$$12 : 22.4 = x : 210.000 \qquad x = 112{,}500 \text{ (ounces)}$$

$$\frac{112{,}500}{32{,}000} = 3.516 \text{ tons}$$

EXAMPLES UNDER GAS VOLUME COMPUTATION, BY EITHER CRITH OR MOLECULAR VOLUME.

These problems have been computed by the molecular (22.4 liter) method in nearly every case. The student is nevertheless recommended to check occasionally by the "crith" method. He must remember, however, that the latter, when 0.09 gram is used as value of the crith, will give slight variants, *i.e.*, as the weight is too great the volume sought will be either too great or too small according to the conditions of the problem.

1. A liter of gas weighs 1.1607 grams. Analysis of the gas is as follows:

Carbon	92.31 per cent.
Hydrogen	7.69 per cent.
(Data indicate C_2H_2)	100.00 per cent.

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It burns to CO_2 and H_2O. Equate the reaction, and calculate total weight of the products of combustion. State also volume of carbon dioxide produced.

$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$ Weight of products = 4.8321 grams

Volume of CO_2 is shown directly, being twice that of the C_2H_2.

2. $H_2 + O = H_2O$. 1000 liters of hydrogen and 400 of oxygen are exploded by the spark. When temperature is reduced again to "normal" (0° C.) what gas remains and what volume of it?

Answer. No calculation is necessary. Read answer directly from data.

3. Same data, but temperature throughout is 100°. What are now the gases and volumes?

Ans. Same for hydrogen. 800 liters steam.

4. What is the weight of 100 liters of nitrogen?

Ans. 125 grams.

5. Illuminating gas has the following *volumetric* analysis:

Carbon monoxide	20 per cent.
Hydrogen	30 per cent.
Methane (CH_4)	40 per cent.
Ethylene (C_2H_4)	10 per cent.
Total	100 per cent.

Equate the consumption of this gas in burning to water and carbon dioxide. Find how many cubic feet of air are required to burn 1000 cubic feet of the gas. (First find how many liters of oxygen are required.)

(200) $CO + O = CO_2$	Oxygen required,	100 cu. ft.
(300) $H_2 + O = H_2O$	Oxygen required,	150 cu. ft.
(400) $CH_4 + 2O_2 = CO_2 + 2H_2O$	Oxygen required,	800 cu. ft.
(100) $C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$	Oxygen required,	300 cu. ft.
Total oxygen required		1350 cu. ft.

If atmospheric air contains 21 per cent. oxygen by volume, then:

$$\frac{1350}{0.21} = 6428 = \text{cubic feet of air required.}$$

For CO_2 gas:	CO (200) produces CO_2	200
	CH_4 (400) produces CO_2	400
	C_2H_4 (100) produces $2CO_2$	200
	Total cubic feet CO_2	800

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Having written the equation, the volumes of oxygen are mere "sight" problems. So are the volumes of CO_2 gas. It is nothing more than a comparison of the respective numbers of molecules.

6. $NH_4NO_2 = 2H_2O + N_2$. Ammonium nitrite decomposes into water and nitrogen gas. If we have 3.5 liters of nitrogen, what weight was taken of the nitrite?

$$64 : 22.4 = x : 3.5$$

Ans. 10 grams.

7. Phosphorus vapor is 4.42 times as heavy as air, which weighs 1.293 per liter. What would be inferred as to its molecular weight?

$1.293 \times 4.42 = 5.71$. (One step omitted.)

Ans. 128, nearly.

8. One liter of SO_2 gas weighs 2.86 grams. What is its molecular weight? Operation omitted. *Ans.* 64.

9. Air contains 79 per cent. nitrogen and 21 per cent. oxygen, by volume. We mix 600 c.c. of air with 50 c.c. CH_4 and explode by the spark.

Regarding the water as condensed, what are the compositions and volumes of the residual gases? (Normal temperature and pressure.)

$600 \times .21 = 126$ = vol. of oxygen
$600 - 126 = 474$ = vol. of nitrogen

The remaining part of the problem is "sight" work.

Ans.

Nitrogen.....	474 c.c.
Oxygen in excess.....	26 c.c.
Carbon dioxide ($= CH_4$)...	50 c.c.
Residual gases, total.....	550 c.c.

10. $4NH_3 = 6H_2 + 2N_2$ Also : $6H_2 + 3\ O_2 = 6H_2O$

Four liters of ammonia gas are dissociated by the spark, and the resulting gas mixture exploded with six liters of oxygen.

What were the volumes of hydrogen and nitrogen after the dissociation? What are the final residual volumes, water aside? (Solve by inspection.)

Ans. (1) hydrogen 6 liters.
nitrogen 2 liters.
(2) nitrogen 2 liters.
oxygen 3 liters.

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11. A liter of oxygen weighs 1.4296, what is its molecular weight?

Mol. wt. : 22.4 = 1.4296 : 1 *Ans.* 32.

12. 20 liters of hydrogen are burnt in 50 liters of air. Water aside, what are the residual gases and their volumes?

Ans. 50 liters air contain 39.5 liters nitrogen, and 10.5 liters oxygen. 20 liters hydrogen require 10 liters oxygen. Residual N = 39.5. O = 0.5.

13. Assuming that the units of molecular weights are equal (as actual weights) in all of the following reactions, give the volumes of all the gases which form their last terms. ("Unit" = 1 gram.)

$KClO_3 = KCl + \ldots\ldots\ldots\ldots\ldots\ldots O_3$* = 33.6 liters.
$MnO_2 + 4HCl = MnCl_2 + 2H_2O + \ldots\ldots Cl_2$ = 22.4 liters.
$HgO = Hg + \ldots\ldots\ldots\ldots\ldots\ldots O$ = 11.2 liters.
$2NaCl + H_2SO_4 = Na_2SO_4 + \ldots\ldots\ldots\ldots 2HCl$ = 44.8 liters.

14. Write out all the volumes of the following reactions, under the supposition that *one molecule* in formula indicates *two liters* in actual volume:

$2CO + O_2 = 2CO_2$.....4 liters + 2 liters, become 4 liters.
$H_2 + Cl_2 = 2HCl$.....2 liters + 2 liters, become 4 liters.
$C_2H_4 + Cl_2 = C_2H_4Cl_2$.....2 liters + 2 liters, become 2 liters.
$CO + Cl_2 = COCl_2$.....2 liters + 2 liters, become 2 liters.
$N_2 + 3H_2 = 2NH_3$.....2 liters + 6 liters, become 4 liters.
$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$..4 liters + 10 liters, become 8 liters + 4 liters.

15. We have phosphorus 0.7557 gram. Find the volume of phosphine gas it will make (PH_3). *Ans.* 0.5546 liter.

PROBLEMS INVOLVING ONE OR MORE OF THE PRECEDING PRINCIPLES

(*a*) $2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$. Two liters of acetylene are exploded with ten liters of oxygen. Aside from water what are the volumes of the gases remaining, *i.e.*, both by combination and excess? (Sight solution.)

Ans. CO_2, 4 liters. Oxygen, 5 liters.

(*b*) $CO + Cl_2 = COCl_2$. One liter of CO and two of chlorine. What volumes and of what gases remain after the reaction?

Ans. Phosgene, 1 liter. Chlorine,1 liter.

* Strictly, according to proper theoretical form, we should not write O_3. Stoichiometrically, it can hardly be misinterpreted.

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(*c*) Four liters of ammonia gas (NH_3), are dissociated by sparking, and then exploded with six liters of oxygen. Aside from water, what are volumes of the residual gases?

Ans. Nitrogen, 2 liters. Oxygen, 3 liters.

(*d*) Phosphine gas in burning produces HPO_3. Write the reaction. *Ans.* $PH_3 + 2\,O_2 = HPO_3 + H_2O$.

(*e*) Phosphorus pentachloride reacts with water, forming orthophosphoric and hydrochloric acids. Write this reaction.

Ans. $PCl_5 + 4H_2O = H_3PO_4 + 5HCl$.

(*f*) Chlorine gas passed into caustic potash (KOH) produces potassium chloride and potassium chlorate. (KCl and $KClO_3$.) Find an equation representing this reaction.

Ans. $6KOH + 3Cl_2 = 5KCl + KClO_3 + 3H_2O$.

(*g*) 16.7192 grams P_2O_5 was derived from what weight of phosphorus? *Ans.* 7.3 grams.

(*h*) $S + O_2 = SO_2$. (S = 32.) What volume of air will burn 1000 grams of sulphur? *Ans.* 3333 liters.

(Air estimated as containing 21 per cent. of its volume of oxygen.)

(*i*) $$S + O_2 = SO_2$$

1000 grams of sulphur are burnt. What volume of SO_2 is produced? *Ans.* 700 liters.

(*j*) $Hg + O = HgO$. 154 grams Hg make what weight of the oxide? *Ans.* 166.32 grams.

(*k*) $$S + H_2 = H_2S$$

Take 6.66 grams sulphur, what *volume* of hydric sulphide is produced? *Ans.* 4.662 liters.

(*l*) $$FeS + H_2SO_4 = FeSO_4 + H_2S$$

We want 100 liters of the gas, what weight of ferrous sulphide must be taken? *Ans.* 392.85 grams.

(*m*) $$Sb_2S_3 + 6HCl = 2SbCl_3 + 3H_2S$$
$$3FeS + 6HCl = 3FeCl_2 + 3H_2S$$

These are two ways of producing sulphuretted hydrogen. Suppose that the antimony sulphide costs eight cents a pound, and the iron sulphide ten cents, which produces the gas more cheaply? *Ans.* The iron sulphide.

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(*n*) 3300 grams of gypsum are heated. What volume of steam at 300° is given off?

$$CaSO_4, 2H_2O = CaSO_4 + 2H_2O$$
$$172 : 22.4 = 3300 : 859.5$$
$$\text{And } \frac{859.5 \times 573}{273} = 1803.6 = Ans.$$

(*o*) Lead is melted in a furnace and a current of air passed over it. $Pb_2 + O_2 = 2PbO$. If the air is admitted at 40° C. how many cubic feet will oxidize 100 lbs. of the lead? (Air has 21 per cent. oxygen by volume.)

$$413.8 : 22.4 = 1600 : 86.6 = \text{cubic feet of oxygen}$$

Lead taken at 206.9 atomic weight. For the proportion, the 100 lbs. become 1600 (ounces). The remaining calculations are omitted. *Ans.* 472.8 cubic feet air at 40° C.

(*p*) In the manufacture of sulphuric acid, we have, through several intermediate reactions, the general result:

$$S_2 + 3O_2 + 2H_2O = 2H_2SO_4$$

If we have two tons of sulphur, what volume of atmospheric air, in cubic feet, must be used? What weight of water? What weight of sulphuric acid will be produced? (Note—Use ounces. 32,000 oz. = one ton.)

Atmospheric air has 21 per cent. by volume of oxygen.

Ans. 1. 320,000 cubic feet of air.
2. 2250 lbs. water.
3. 12,250 lbs. sulphuric acid.

(*q*) $$2C_2H_2 + 5\,O_2 = 4CO_2 + 2H_2O$$

In this combustion six liters of acetylene gas take part. How many liters of atmospheric air (21 per cent. by vol. of oxygen) will be required?

What will be the volume of carbon dioxide? What will the latter weigh in grams? What will the water weigh?

Answers. (1) $71\frac{3}{7}$ liters of air. (2) Vol. of carbon dioxide, 12 liters. (3) Weight of CO_2, 23.57 grams. (4) Weight of water, 4.82 grams.

(*r*) A mixture of oxygen, carbon dioxide, carbon monoxide, and hydrogen, contains equal volumes of each gas. Find the analysis by weights.

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(Note that the expressions for equal volume must be written with due regard to equal number of molecules, *i.e.*, O_2, CO_2, CO, and H_2.)

Ans.

Oxygen	30.19 per cent.
Carbon dioxide	41.51 per cent.
Carbon monoxide	26.41 per cent.
Hydrogen	1.89 per cent.
	100.00 per cent.

(*s*) A mixture of gases has the following composition by weight:

Oxygen	59.02 per cent.
Hydrogen	4.92 per cent.
Carbon dioxide	36.06 per cent.
	100.00 per cent.

Deduce analysis by volume.

(Divide each percentage by either molecular weight or density, then reduce to volumes by percentage.)

Oxygen	36.0 per cent.
Hydrogen	48.0 per cent.
Carbon dioxide	16.0 per cent.—100.0 *Ans.*

(*t*) $$4KNO_3 + 5C = 2K_2CO_3 + 2N_2 + 3CO_2$$

If in this reaction four liters of nitrogen are evolved, what is weight in grams of the nitrate, and what is volume in liters of the dioxide?

Answers. Weight of nitrate, 36.07 g.; vol. of dioxide, 6 liters.

(*u*) Nitrogen tetroxide at 180° C. and upward is 1.57 times as heavy as air. (Air weighs 1.293 grams per liter.) What molecular weight does this show, and why is this supposed to indicate a different constitution from its greater density at less temperature?

Ans. Molecular weight would be $1.293 \times 1.57 \times 22.4 = 45.47$. This is close to 46, theoretical molecular weight of NO_2.

At less temperatures, the greater density indicates approach to the double formula N_2O_4.

(*v*) $KClO_3 = KCl + O_3$. KCl remaining weighed 32.78 grams. Give weights of $KClO_3$ and oxygen, also volume of the latter.

Answers. $KClO_3$, 53.9 grams. Oxygen, 21.12 grams, 14.784 liters.

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(*w*) A liter of ferric chloride vapor, reduced to 0° and 760 mm., weighs 14.56 grams. What is the molecular weight?

$$\text{Mol. wt.} : 22.4 = 14.56 : 1 \text{ (liter)}$$

Ans. 326+.

(*x*) $$P_2 + 5Cl_2 + 8H_2O = 10HCl + 2H_3PO_4$$

Using 20 grams phosphorus, what volume of chlorine at 15° C. was used? *Ans.* 38.114 liters.

What volume of HCl gas produced (at sight from last answer)? *Ans.* 76.228 liters.

Same equation: Liters of chlorine used, measured at 17° C. = 1.3433.

What was weight of the phosphorus? *Ans.* 0.7 gram.

(*y*) One liter each of hydrogen, methane, ethylene, acetylene, carbon monoxide, and phosphine, are burnt. State volumes of oxygen respectively necessary for complete combustion.

$2H_2 + O_2 = 2H_2O$	Oxygen = 0.5 liter.
$CH_4 + 2O_2 = CO_2 + 2H_2O$	Oxygen = 2 liters.
$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$	Oxygen = 3 liters.
$2C_2H_2 + 5O_2 = 4CO_2 + 2H_2O$	Oxygen = 2.5 liters.
$2CO + O_2 = 2CO_2$	Oxygen = 0.5 liter.
$2PH_3 + 4O_2 = P_2O_5 + 3H_2O$	Oxygen = 2 liters.

(This is a "sight" problem. The coefficients have been so adjusted that no rule of molecular symbolism is violated. We have only to remember that each symbol to the left indicates one liter, concretely, the oxygen appears at once.)

(*z*) $$NH_4NO_2 = 2H_2O + N_2$$

What volume of nitrogen from 7 grams of the ammonium nitrite?

$$64 : 22.4 = 7 : x = 2.45 \text{ liters}$$

(*a**) What does one liter of silicon chloroform weigh at 180° C? (Exact wts.)

$$SiHCl_3, \text{ molecular weight} = 135.758$$

$$\frac{V \times \text{m. w.}}{22.4} = 6.0606 \text{ grams, at 0° C. (180° C. = 453° absolute.)}$$

$$273 : 453 = 1 : 1.659$$

That is, one liter at 0° becomes 1.659 liters at 180° C. Finally:

$$1.659 : 1 = 6.0606 : 3.65 = \text{weight of one liter at 180° C.}$$

(*b**) $$Br_2 + H_2S = S + 2HBr$$

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217 grams of bromine dissolved in water, and sulphuretted hydrogen is passed into the solution. What volume of the gas at 15° C. is required? What would be the volume of the HBr, as gas, at the same temperature?

$$160 : 22.4 = 217 : 30.38$$
$$273 : 288 = 30.38 : 32.049 \text{ liters } H_2S \text{ at } 15° \text{ C.}$$

Read volume HBr at sight from data and first answer.

(*c**) $10\ I_2 + 2P_2 + 8KI + 16H_2O = 4K_2HPO_4 + 28HI$

We want 10 liters of gaseous hydrogen iodide (hydriodic acid) at 15° C. Find necessary weights of iodine, potassium and phosphorus.

In this as in all similar cases we must first get the volume of the gas at normal temperature and then calculate the equation.

$$288 : 273 = 10 : 9.479$$

In calculating the relation by gas volume, it makes no difference which of the solids in the first member we employ. Let us take the iodine.

$$2540 : 22.4 \times 28 = x : 9.479 \qquad x = 38.38 \text{ grams iodine}$$

We then get the others by simple ratio of the proper "weights," *i.e.*,

$$10\ I_2 : 2P_2 = 2540 : 124 = 38.38 : x = 1.87 \text{ phosphorus}$$
$$10\ I_2 : 8KI = 2540 : 1328 = 38.38 : y = 20.06 \text{ K iodide}$$

(*d**) $2P_2 + 3KOH + 3H_2O = 3KH_2PO_2 + PH_3$

This reaction evolved 143.5 liters of phosphine at 37° C. What weight of phosphorus was used? *Ans.* 70 grams.

(*e**) 135 c.c. gas at 17° C. and 600 mm. pressure, become 90 c.c. at 0° C. What is the pressure? *Ans.* 847 mm.

(*f**) 840 c.c. gas at 27° C. and 500 mm. become 720 c.c. at 760 mm. pressure. What is the temperature?

Ans. 117.9° C.

(*g**) 0.2726 liter air weighs 0.3 gram at 37° C. What is the pressure?

First reduce to 0° C.; this gives 0.2401 liter (weighing 0.3).

Then:

$$0.2401 : 1 = 0.3 : 1.249 \text{ gram}$$

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(Air at "normal" temperature and pressure weighs 1.293 grams per liter.)

$$1.293 : 1.249 = 760 : 734$$

Ans. Pressure = 734 mm.

(*h**) 100 liters of air at 760 mm. weigh 124 grams.

What is the temperature? (Densities are inversely as temperatures.)

$$124 : 129.3 = 273 : 284.7 \text{ (absolute)}$$

Ans. 11.7° C.

(*i**) At what temperature does one liter of air weigh one gram? *Ans.* 80° C. (nearly)

(*j**) $CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$

This yields 20 liters of CO_2 gas at 18° C. and 740 mm. What weight of the calcic carbonate was taken? The 20 liters make 18.27 at "normal," then:

$$100 : 22.4 = x : 18.27 \qquad x = 81.56 \text{ grams}$$

N. B.—Some of the above problems indicated by * involve Boyle's and Charles' laws, and should be passed over until the latter have been explained.

Density of Gases Compared with Air as Unity.

This method of stating gas density is now little used. By fixing the weight of a liter of air in the memory, also the density of air on the scale $O_2 = 32$, any desired transformation may be readily made.

Weight of one liter of air = 1.293 gram (at 0° C. and 760 mm.).

Density of air, on scale $O_2 = 32$, is 28.95.

Given density of a gas on scale air = 1, the weight of one liter of the gas is found by multiplying density by 1.293.

Given density of a gas on scale $O_2 = 32$, the weight of one liter is found as in the above rules, by dividing density by 22.4. (More closely, 22.38.)

Given density on scale air = 1 to find density on scale $O_2 = 32$, multiply by 28.95.

Given density on scale $O_2 = 32$ to find density on scale air = 1, divide by 28.95.

Examples.—1. Nitrogen referred to air has density 0.967. What is the weight of one liter?

Ans. $0.967 \times 1.293 = 1.250$ gram.

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2. Carbon dioxide referred to $O_2 = 32$, has density 44. What is weight of one liter? *Ans.* $44 \div 22.4 = 1.964$ gram.

3. Ammonia (air = 1) has density 0.588. What is its density on scale $O_2 = 32$? *Ans.* $0.588 \times 28.95 = 17.02$.

4. CO gas ($O_2 = 32$) has density of 28. What is its density on scale of air = 1? *Ans.* $28 \div 28.95 = 0.967$.

Charles' Law.

"The volume of a mass of gas varies directly as the absolute temperature to which it is exposed."

Problem VIII.—Given the volume of a stated mass of gas, at a certain temperature, to find its volume under a given change of temperature.

It was long ago observed that if a volume of gas *at the temperature of zero Centigrade*, were subjected to changes of temperature, *pressure remaining constant*, it changed its volume *one two hundred and seventy-third of its volume at zero for each degree of temperature.*

For example, assuming 273 volumes at zero, if the temperature be raised to 8°, the volume will become 281. Similarly, if the temperature drops to −10°, the volume contracts to 263.

This fact suggested the "absolute zero" convention. On this thermometric scale "zero" is placed at a point 273° below the Centigrade zero, *the size of the degree remaining the same.*

Ice melts at 273° "absolute." Water boils at 373°. In short, the *interval in degrees* between any two points of observed temperature remains unchanged.

Thus, instead of saying (as we have to in using the Centigrade scale) that "a gas expands or contracts one two hundred and seventy-third of its volume at zero for each change of one degree in temperature," we reduce the terminology to the simplicity of the law, by saying merely that gases expand or contract "directly as the temperature."

In all questions, then, involving new gas volumes under changed temperature, we first convert Centigrade into "absolute." This is easy, as it consists in simply adding 273 to the Centigrade degrees.

65° C. = 338° Abs. 0° C. = 273° Abs. −40° C. = 233° Abs., etc.

Hence rule for the solution of Problem VIII.

"First convert temperature into degrees absolute, then write the proportion, placing volumes and degrees in equalized ratio."

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Any of the four quantities involved may be the unknown, *i.e.*, present volume or new volume of the gas, present or new temperature to which it may be subjected.

Example.—Volume of gas at 4° C. is 100, what will it be at 281° C.?

Add 273 to each of the Centigrade temperatures, making them "absolute."

4 + 273 = 277 for the first. 281 + 273 = 554 for the second.

$$T : T' = V : V'$$
$$277 : 554 = 100 : 200$$

Ans. New vol. = 200.

(*b*) Same data inverted. Starting from 4° C. what temperature is required to double the volume of the gas?

4 + 273 = 277. And 277 × 2 = 554 (absolute)

If the answer is to be in Centigrade degrees, then, 554 − 273 = 281° C.

(*c*) What temperature will raise 100 vols. at 15° C. to 140 vols.?

First : 15 + 273 = 288 "absolute" degrees corresponding to 15° C.

100 : 140 = 288 : 403.2 (Abs.) 403.2 − 273 = 130.2° (C.)

(*d*) A liter of oxygen weighs, at 0° C., 16. What will it weigh at 91° C.?

$$273 : 364 = 1 : 1\tfrac{1}{3}$$

The mass of course has not changed, so one liter of the gas at new temperature, being $\frac{3}{4}$ of $1\frac{1}{3}$, the weight of a liter of oxygen at the new temperature will be $\frac{3}{4}$ of 16, or twelve. *Ans.* 12.

(What is the unit of weight, may be asked. It matters not.)

Throughout this section we are speaking of change in temperature under constant pressure.

(*e*)

If	volume of gas at	0° Centigrade = 1000
Then	volume of gas at	10° Centigrade = 1036
	volume of gas at	20° Centigrade = 1073
	volume of gas at	30° Centigrade = 1110
	volume of gas at	40° Centigrade = 1146
	volume of gas at	50° Centigrade = 1183
	volume of gas at	60° Centigrade = 1220
	volume of gas at	70° Centigrade = 1256
	volume of gas at	80° Centigrade = 1293
	volume of gas at	90° Centigrade = 1330
	volume of gas at	100° Centigrade = 1336

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Generally, any continuation of this table may be obtained by:

$$\frac{1000 \times (273 + x)}{273}$$

For example, required volume at 30° we have $1000 \times (273 + 30) = 303{,}000$.

And $\frac{303{,}000}{273} = 1{,}110$ as in the table.

This merely illustrates the "273" fact, without direct resort to the "absolute" zero convention.

By taking volumes or temperatures from various places in the table the student may construct any number of little problems to be used as check work. They should be done by the "absolute" temperature method.

Examples are not extended, as many are scattered through the text.

Boyle's Law.

"The volume of a mass of gas varies inversely as the pressure on it."

Problem IX.—Given the volume of a certain mass of gas, to find the volume under a given change of pressure.

Pressure is usually expressed in barometric millimeters.

Since the volume is inversely as the pressure, if we designate the given volume as V, and the given pressure as P, while the new volume is V' and the new pressure is P', the proportion is

$$V : V' = P' : P$$

Rule.—Place volumes and corresponding pressures in inverse ratio.

(We use inches in barometric readings in the first examples.)

Examples.—(*a*) Volume of gas at 30 inches barometer is 1. What will it be at 24 inches?

$$V : V' = P' : P$$
$$1 : x = 24 : 30 \qquad \textit{Ans.}\ x = 1.25.$$

(*b*) Volume at 15 inches being 75, at what pressure will volume become 60?

$$75 : 60 = x : 15 \qquad \textit{Ans.}\ x = 18.75.$$

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(*c*) Find volume of gas, now at 30 inches barom., which at 12 inches had volume 3750.

$$x : 3750 = 12 : 30 \qquad \textit{Ans.}\ x = 1500.$$

(*d*) Volume of gas is now 30. It was 75 at 22 inches, what is now the pressure?

$$30 : 75 = 22 : x \qquad \textit{Ans.}\ x = 55.$$

Or, generally,

$$a : x = b : c \text{ and } x = \frac{a \times c}{b}$$

Any quantity may be the unknown, as under last rule.

Millimeters are used in the following example.

(*e*) A closed vessel, *displacing one liter** is tared, barometer being at 760 mm. Barometer falls to 710 mm.

What weight will now restore the equilibrium, and on which side of the balance will it go? (Temperature constant at 0° C.)

NOTE.—1 liter of air under "normal" conditions, *i.e.*, 760 mm. pressure and 0° C. temperature, weighs 1.293 gram.

$$760 : 710 = 1.293 : 1.208$$

that is, a liter of air, pressure 710, weighs 1.208 gram.

$$1.293 - 1.208 = 0.085 \text{ (85 milligrams)}$$

The air that is being "weighed" here is outside of the vessel. It is, in fact, the volume of air which the vessel "displaces." For the vessel being closed, the weight of its contents has not changed.

But the apparent weight of the vessel increases, because the medium surrounding it has become lighter. The proportionate weight of the atmosphere (density) is a function of the pressure.

The weight, then, must be placed on the scale pan *opposite* the vessel.

---

* This indicates that the *exterior* size of the vessel is equal to one liter, instead of its contents. Hence, as it stands on the balance, the vessel may be said to "displace" one liter of the atmosphere which surrounds it.

Several similar cases will be found among the "Miscellaneous Problems" at the end of the text.

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Laws of Charles and Boyle Combined.

It is rare, in the application of the rules for changes in volume, that we do not have to apply them for both temperature and pressure, in other words, for variations in both thermometer and barometer.

Ordinarily these rules are used separately, *i.e.*, the change of volume is figured from one change only, the result is then taken as an initial volume, and its new volume figured by the application of the rule for the other physical variation. It makes not the slightest difference whether the correction be applied first for pressure and then for temperature, or in the reverse order. This is too "rationally" obvious to demand any proof.

Example.—(*a*) 320 cubic centimeters of gas, pressure 950 mm., temperature 91° C., to be reduced to volume at 760 mm. pressure and 0° Centigrade.

First apply the rule for temperature (Charles).

$$91 + 273 = 364. \quad 0 + 273 = 273. \quad \text{(Abs. degrees, 364 and 273.)}$$
$$364 : 273 = 320 : x \qquad x = 240$$

Now take this volume, 240 c.c, and treat it as initial volume. Compute its change in passing from 950 to 760 mm. pressure (Boyle).

$$760 : 950 = 240 : 300 \quad \textit{Ans. 300 cubic centimeters}$$
new : old = old : new. "Vols. *inversely* as pressures"

(*b*) 100 vols. at 27° C. and 720 mm.

What vol. at 42° C. and 756 mm.? (Begin with rule for pressure.)

$$756 : 720 = 100 : 95.23895 \text{ (vol. under changed pressure)}$$

Absolute degrees are $27 + 273 = 300$, and $42 + 273 = 315$.

$$300 : 315 = 95.2389 : 100 \qquad \textit{Ans. No change in volume.}$$

Formulistic Combination of Charles' and Boyle's Laws.

We have shown how to apply the formulæ separately, getting correction for both temperature and pressure. It is quite easy, however, to apply a single formula for the double correction, although little is gained by so doing.

Suppose V, P, T to represent the original volume, pressure and temperature of a certain mass of gas. Let v, p, t represent

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the volume, pressure and temperature after both computations have been made, *i.e.*, after allowing for changes in *both* temperature and pressure.

Let us first go through the "successive" operations, beginning with the change in temperature, seeking the new volume *under this change alone.*

We have, of course:

$$T : t = V : x$$

$$x = \frac{Vt}{T}$$

This is the volume of gas under change of *temperature* alone, and it is this volume that we are now to submit to computation for change in *pressure.* Under this final change, remember that the volume is assumed as "v," the final pressure being "p." By the rule as given, substituting value of "x":

$$p : P = \frac{Vt}{T} : v \qquad \text{Hence, } v = \frac{VPt}{Tp}$$

We may regard any of the quantities v, t, p, as unknown, and several of the problems hereafter given are so constructed. We shall have:

$$v = \frac{VPt}{Tp} \qquad t = \frac{Tvp}{VP} \qquad p = \frac{VPt}{Tv}$$

This formula, however, does not diminish the arithmetical work. Looking, *e.g.*, at the fractional value of "v," we see in it all of the operations of the "successive" applications of the corrections for both physical changes.

Any of these expressions may be readily reduced to the general form:

$$\frac{vp}{t} = \frac{VP}{T}$$

This is a good "mnemonic" form, on account of its perfect symmetry. Value of any of the factors in terms of the others can be derived from it by a simple transformation.

Examples.—(*a*) 120 c.c. of gas at 0° C., and 740 mm. pressure, become 125.4 c.c. at temperature of 20° C. What is the new pressure?

(Remember that the temperatures are 273° and 293° "absolute.")

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$V=120.$ $v=125.4.$ $T=273.$ $t=293.$ $P=740.$ Find "p."

$$p = \frac{VPt}{Tv}$$

$$(120 \times 740 \times 293) \div (273 \times 125.4) = 760$$

Ans. 760 mm.

Vary this and the following problems by changing about the data, making first one and then another the "unknown."

(*b*) A volume of gas at 60° C. and 30 inches barometer has volume of 109.57 when temperature is 5° C., pressure 24 inches. What original volume?

NOTE.—Take the latter three figures as V, P, T, and the first two as t, p. This avoids transformation of the formula.

$V=109.57.$ $T=278.$ $t=333.$ $P=24.$ $p=30.$ Find "v."

$$v = \frac{VPt}{Tp}. \quad (109.57 \times 24 \times 333) \div (278 \times 30) = 105 \textit{ original vol.}$$

(*c*) One liter of air at 30 in. barometer and 136.5° C. becomes what volume at 20 in. bar., and 0° C.? (Absolute temperatures, 409.5 and 273.)

Formula as in (*b*):

$$(1 \times 30 \times 273) \div (409.5 \times 20) = \frac{8190}{8190} = \text{unity}$$

Ans. No change in volume.

The student is recommended to abandon the strictly "formulistic" solution of these cases when he has become thoroughly accustomed to the logic. There is less liability to error when the "rationale" is followed than when a formula is blindly applied. Treat the whole matter as a case of multiplication by fractions, *e.g.:*

A liter of gas at 7° and 740 mm. has what volume at 0° and 760 mm.?

$$1 \times \frac{273}{280} \times \frac{740}{760} = 0.9494$$

We know that the less temperature will *decrease* the volume, so we put the temperatures into a "proper" fraction. The greater pressure will also decrease the volume, so we put pressures into a proper fraction.

Evidently all the facts and formulæ are involved in this simple procedure. Experience has shown it to be "safer" also.

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Examples.—(*a*) 0.700 liters at 27° and 1000 mm. have what volume at 0° and 760 mm.?

$$0.700 \times \frac{273}{300} \times \frac{1000}{760} = 0.838$$

(*b*) We have 1.110 liters at 0° and 760 mm., at what pressure will it reduce to a liter?

$$p = 760 \times 1.110 = 843.6$$

(*c*) We have 0.750 liter at 27° and 700 mm., at what temperature will the volume become one liter?

$$\frac{300}{.75} = 400 \text{ (}i.e.\text{, 127° Centigrade)}$$

In fact, the blunder against which we chiefly warn is forgetting to transform centigrade into absolute degrees, for the operation, and back again, in the answer. (Add in the first case, subtract in the second.)

Weights of Gases under Variations in Temperature and Pressure.

Problems involving weight of any given volume of gas must include in the data, the weight of a liter of that gas under "normal" conditions. Variations due to temperature and pressure are the same for all gases, but *density* is a special factor for each gas. Carefully avoid the fallacy of changed weight for the *same mass* of gas, a precaution not so absurd as it looks.

It will aid the solution especially by short cut method, to remember that *density is directly as pressure.* If a liter of gas weighs a gram, then at double the pressure it will occupy volume of half a liter, and its density will be doubled. A liter at the new pressure would weigh two grams.

Examples.—(*a*) What will a liter of nitrogen weigh at 30° and 640 mm.? (A liter at 0° and 760 mm. weighs 1.25 grams.)

Reduce first to "normal" conditions:

$$1 \times \frac{273}{303} \times \frac{64}{76} = 0.7587 \text{ liter}$$

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Now we have only to multiply by the "normal" weight per liter. For the mass remains the same. $0.7587 \times 1.25 = 0.9484$ weight of the gas.

(*b*) Suppose some other than volume to be the unknown, *e.g.*, a liter of air at 17° C. weighs 1.180, what is the pressure?

(A liter of air weighs 1.293 under "normal" conditions.)

Let us do this "rationally" first, and then use the formula. The volume of this air (pressure unchanged) at 0° is $\frac{273}{290}$ or 0.9414 liter: its weight is unchanged, but a liter *under the same conditions* would weigh 1.253, that is, $\frac{1.18}{9414}$, so that the problem has now become a simple proportion:

$$1.293 : 1.253 = 760 : p. \qquad (p = 736+)$$

The factors which have been used for this result being now assembled, we see that

$$p = \frac{290 \times 760 \times 1.18}{273 \times 1.293}$$

If now P, T, and W indicate "normal" data, and p, t, w the new data (W and w standing for weights), we have:

$$p = \frac{tPw}{TW}$$

W being weight of one liter under "normal" conditions.

Compare with formulistic value of p in previous article, where we had

$$p = \frac{VPt}{Tv}$$

"V" and "v" are no longer present, but we have reciprocal factors of weight-for-volume (density). Being reciprocal, they take respectively reverse places in the fraction, density corresponding to V appears in the denominator, while that corresponding to v is now in the numerator.

The student will easily learn to use these data without formal substitution. The remarks already made as to a "sense of magnitude" apply here. Errors creep into computations of every kind, but they will be multiplied if the worker has not with him a corrective sense which raps his brain at a false move.

The following two examples and their inversions are carried out in detail and without formulæ, as type cases.

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(*c*) What is the weight of one liter of ammonia gas, at 30° C. and 900 mm.?

The normal weight of the gas per liter (0° and 760 mm.) is 0.76.

First we find weight at 0° of 1 liter at 900 mm. pressure:

$$760 : 900 = 0.76 : 0.90 = \text{wt. of 1 liter at 900 mm.}$$

Next apply correction for temperature:

$$273 : 303 = x : 1.11 = \text{vol. at 30° and 900 mm.}$$

This 1.11 is merely a suppositious volume, *i.e.*, *if* we had a liter at 900 mm. and 0°, it would have volume of 1.11 at 30°. But by the data we have vol. of 1 liter under the conditions named, hence the proportion.

$$1.11 : 1 = .9 : x \qquad \textit{Ans.}\ x = 0.8109 \text{ gram.}$$

By inverting the problem, we get both a new problem and a check on the above, viz:

(*d*) We have 0.8109 gram of ammonia gas, what will be its volume at 30° C. and 900 mm.?

First find volume of this weight at "normal" condition.

$$.76 : .8109 = 1 : x \qquad x = 1.067 \text{ liter.}$$

Apply temperature.

$$273 : 303 = 1.067 : 1.1842 = \text{vol. at 30°}$$

Apply pressure.

$$900 : 760 = 1.1842 : x \qquad x = 1 \text{ liter.}$$

(*e*) Pressure on 1 liter of HCl gas is 1000 mm., and its weight is 1.8 gram. What is the temperature C.? (Normally, 1 liter HCl weighs 1.628 gram.)

$$760 : 1000 = 1 : x \qquad x = 1.316$$
$$1.628 : 1.8 = 1 : 1.1057, \text{ and } 1.1057 : 1.316 = 273 : 325$$

Subtract 273 from this "absolute" temperature.

$$\textit{Ans.}\ 325 - 273 = 52° \text{ C.}$$

(*f*) Inversion and proof of (*e*). One liter of HCl being at 52° C., and 1000 mm. pressure, what is its weight?

$$760 : 1000 = 1 : 1.316 = \text{vol. at 760 mm. and 52° C.}$$
$$325 : 273 = 1.316 : 1.1057 = \text{vol. at 0° C.}$$
$$V : v = W : w, \text{ that is, } 1 : 1.1057 = 1.628 : 1.8 \quad \text{Ans.}$$

Some of the steps are purposely left without explanation.

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SPECIFIC GRAVITY.

The **Specific Gravity** of a substance is the weight of any given volume of it, as compared with the weight of the same volume of a substance taken as the standard of comparison.

We reserve the term "Density" for gases. The standard substance adopted for comparison in solids and liquids is *water at its greatest density*, which is at 4° C. Barometric pressure of 760 mm. is also understood, though this has very little influence in ordinary determinations of specific gravity.

Determinations are usually made at ordinary temperatures, and if great accuracy is called for, reduction to standard conditions may be made afterward.

Another consideration comes in, for accurate work, viz: the fact that the substance under investigation has not the same specific gravity as the weights used for the determination. Hence the displacement of air is unequal. Theoretically, then, specific gravity determinations should be made "in vacuo." This not being practicable, another reduction should be made, allowing for the difference between the figures obtained, and what they would have shown had it been possible to perform the necessary operations in an actual vacuum. These differences are rarely taken into the account except in those exceptional cases where minute differences in specific gravity under slightly variant conditions are to be recorded.

Water is 773 times as heavy as air. It is evident that the correction would be greatest when the substance greatly differs in specific gravity from the weights used.

In practice it is usual to consider the comparison as made between weights with one gram as the weight unit and one cubic centimeter as the volume unit.

Since one cubic centimeter of water, under the conditions above specified, weighs one gram, this convention brings about the convenient identity *in figures*, of actual weight in grams with specific gravity.

Example.—One c.c. of water weighs one gram. Sp. gr. = 1. One c.c. of copper weighs 8.85 grams. Sp. gr. = 8.85.

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Having agreed upon this convention, we might define specific gravity by the figures representing the *weight of one cubic centimeter of the substance.*

Elementary principles of physics show that the weight of a body is the product of its specific gravity by its volume. This finds its easiest practical expression in the metric system, owing to the connection by simple relations between linear and volumetric measures, and between the latter and weights, standard (water) having once been adopted.

We do not go into the definition of "mass" as distinct from "weight."

A few examples are appended illustrating the principle mentioned, viz: $W = V \times G$, where W = weight, V = volume, and G = specific gravity.

Special problems on gravity determinations follow in order.

Problems.—These substitutions are hardly "problems." Any two of the quantities W, V, G being given the third follows. We have only to remember:

$$W = V \times G \qquad V = \frac{W}{G} \qquad G = \frac{W}{V}$$

Any two, then, of the quantities in the following examples may be taken as the given or known data, the third one becomes the "unknown."

(*a*)	$V = 732.0$	$G = 0.89$	$W = 651.48$
(*b*)	$V = 650.0$	$G = 1.01$	$W = 656.50$
(*c*)	$V = 232.0$	$G = 1.84$	$W = 426.88$
(*d*)	$V = 38.56$	$G = 0.81$	$W = 31.2336$
(*e*)	$V = 62.7$	$G = 1.23$	$W = 77.121$
(*f*)	$V = 250.6$	$G = 0.98$	$W = 245.588$
(*g*)	$V = 36.7$	$G = 2.01$	$W = 73.767$
(*h*)	$V = 62.9$	$G = 0.97$	$W = 61.013$
(*i*)	$V = 611.0$	$G = 13.4$	$W = 8187.4$
(*j*)	$V = 722.0$	$G = 3.03$	$W = 2187.66$
(*k*)	$V = 13.75$	$G = 1.2$	$W = 16.50$
(*l*)	$V = 86.5$	$G = 1.32$	$W = 114.18$
(*m*)	$V = 11.6$	$G = 2.17$	$W = 25.172$
(*n*)	$V = 0.91$	$G = 1.25$	$W = 1.1375$
(*o*)	$V = 20.50$	$G = 0.90$	$W = 18.45$
(*p*)	$V = 14.00$	$G = 1.27$	$W = 17.78$
(*q*)	$V = 222.00$	$G = 4.19$	$W = 930.18$
(*r*)	$V = 321.00$	$G = 0.95$	$W = 304.95$
(*s*)	$V = 932.00$	$G = 0.86$	$W = 801.52$

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Problem X.—Ordinary specific gravity determination, by weighing in both air and water. The substance, having been weighed in the usual manner, is suspended by a fine thread from the balance arm, lowered into water by suitable appliances, and "weighed" in water. *Apparent loss of weight* is then made the means of calculating specific gravity. Neglect correction for weight of the air. The substance in this operation must of course be heavier than water. (See later for substances lighter than water.) The substance manifestly displaces a volume of water equal to its own volume, so that we at once derive the rule: "*Divide weight in air by loss of weight in water.*"

It is obvious that the "loss of weight" is simply the *weight of a volume of water equal to the volume of the substance.*

Let G = sp. gr., W = weight in air, and W' weight in water. Then the apparent "loss of weight" will be $W - W'$. It is further evident that the weight of any volume of water is to unity (sp. gr. of water) as the weight of the same volume of any other substance is to its sp. gr., that is:

$W - W' : 1 = W : G$. Hence (as by rule above):

$$G = \frac{W}{W - W'}$$

Examples:

(*a*)	$W = 6.3245$	$W' = 5.0596$	$G = 5.00$
(*b*)	$W = 37.8182$	$W' = 21.1582$	$G = 2.27$
(*c*)	$W = 28.9344$	$W' = 20.4864$	$G = 3.4250$
(*d*)	$W = 5.5748$	$W' = 4.3078$	$G = 4.4$
(*e*)	$W = 3.9144$	$W' = 0.6524$	$G = 1.2$
(*f*)	$W = 86.8371$	$W' = 82.7020$	$G = 21.0$
(*g*)	$W = 25.92$	$W' = 17.92$	$G = 3.24$
(*h*)	$W = 94.800375$	$W' = 86.373675$	$G = 11.25$
(*i*)	$W = 37.638408$	$W' = 0.738008$	$G = 1.02$
(*j*)	$W = 16.037$	$W' = 4.234$	$G = 1.3587$
(*k*)	$W = 22.224$	$W' = 20.308$	$G = 11.599$
(*l*)	$W = 21.424$	$W' = 19.848$	$G = 13.59+$

Problem XI.—To find the specific gravity of a substance soluble in water. In this case the substance may be weighed in a liquid in which it is not soluble. This liquid may be either lighter or heavier than water, but for convenience in operations it should be lighter than the substance. See next problem.

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The specific gravity of the liquid must of course be known. It may be necessary to determine it, as in problem to be presently given for determination of sp. gr. of liquids.

Call the specific gravity of the liquid "*a*." Call the specific gravity *with reference to this liquid* ("apparent specific gravity") "*g*." Call as above the *true* specific gravity (*i.e.*, referred to water), "*G*." We now have (since sp. gr. of water = 1):

$$1 : a = g : G \text{ and } G = a \times g$$

Rule.—Multiply sp. gr. of the liquid by (apparent) sp. gr. of the solid in the liquid. The latter is deduced by the last rule.

Examples:

	"a."	Wt. in air.	Wt. in liquid.	G.
(*a*)	0.8	2.752	2.064	3.2
(*b*)	0.85	3.393	2.262	2.55
(*c*)	0.9375	2.7232	1.8722	3.00
(*d*)	1.2	8.47	7.00	6.91+
(*e*)	0.9	21.6	15.6	3.24
(*f*)	0.86	10.5	8.2	3.92
(*g*)	1.6	12.2	10.6	12.20
(*h*)	0.92	14.2	11.6	5.02
(*i*)	0.88	6.4	5.8	9.39
(*j*)	1.33	12.42	8.82	4.59
(*k*)	0.82	20.6	14.2	2.64
(*l*)	0.92	6.0	3.0	1.84

Problem XII.—To determine the specific gravity of a substance lighter than water.

Attach the light body to a heavy one, and weigh the pair together in water. Also weight of the heavy body *alone* in water must be determined. As in all other cases, the weight of the body under investigation must be found, under usual conditions, viz: "in air."

A piece of metal, heavy enough for all probable cases, may be selected and weighed in water "once for all." Silver, as being practically unalterable by air and damp, is the best. *Note that it is unnecessary to determine weight of the heavy body in air.*

It is evident that the combined apparent weight of the pair, in water, must be less than the weight of the heavy body alone, in water. We may call the loss of weight in water (as compared with weight of the heavy body alone) the "buoyancy" of the

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light body. The weight of a bulk of water *equal in volume to the solid*, is the fundamental datum as in the first case. The weight of this bulk of water is the *sum* of the weight in air of the solid, *plus* its apparent *minus weight* (buoyancy) when attached to the heavy body.

Examples.—(a):

Weight of the heavy body in water	6.3584
Weight of both bodies on water	5.8880
"Buoyancy" of the light body	0.4704
Weight of the light body in air	0.5096
Weight of volume of water equal to that of solid	0.9800

Now we have the "data" of the original problem, viz: weight of the solid, and weight of an equal volume of water, so that the specific gravity is deduced at once as in the previous case.

$$\frac{.5096}{.9800} = 0.52 = \text{sp. gr.} \left(\frac{W}{V} = G\right)$$

The figure 0.98 is an expression for volume as well as weight; a point in metric convenience which the student may well note.

Wt. of heavy body in water.	Both, in water.	Light, in air.	Sp. gr.
(*b*) 6.1342	5.8408	0.5216	0.64
(*c*) 4.3186	3.7570	1.7784	0.76
(*d*) 22.0632	17.0365	5.0267	0.50
(*e*) 6.42	5.90	2.60	0.83
(*f*) 16.40	15.94	1.60	0.777
(*g*) 10.2	8.8	1.4	0.50

Problem XIII.—To determine the specific gravity of a liquid.

Special apparatus is used for this determination. For close work a tared flask holding a certain weight of water to the tip of its perforated stopper, may be filled with the liquid. The net weight gives sp. gr. directly, if the weight of the water is a power of ten (10 or 100). $t°$ C. is marked on flask.

The instruments known as "hydrometers" and by other names, which are dropped into the liquid placed in a cylinder, are well known. Those of smaller range are the more delicate. All alike have readings marked on their "stems."

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These devices, however, being appliances for yielding results without calculation, need not here be dwelt upon.*

The sp. gr. of a liquid may be determined thus:

Weigh a solid (1) in air, (2) in water, (3) in the liquid. We may use the same solid for every determination, thus saving operations (1) and (2).

Call these three weights W, W', and W'', then we have:

$$W - W' : W - W'' = 1 : G = \text{sp. gr. of the liquid}$$

Examples.—(*a*):

Solid in air,	3.393		3.393
Solid in water,	2.063	In liquid,	2.262
	1.330		1.131

$$1.330 : 1.131 = 1 : 0.85 = \text{sp. gr. of the liquid}$$

	W.	W'.	W''.	*Sp. gr. of liquid.*
(*b*)	6.7672	5.8336	5.2020	1.676
(*c*)	14.0	12.0	11.2	1.4
(*d*)	10.2	6.7	8.45	0.5
(*e*)	30.0	25.0	20.0	2.0
(*f*)	4.6	3.2	3.8	0.57
(*g*)	8.8	7.6	6.4	2.00

Problem XIII (2nd case).—Having a liquid of given sp. gr. "*a*" (greater than 1), how much water must be added to bring it to sp. gr. "*b*"? (No allowance for condensation or expansion.) Let x = c.c of water to be added to 1 c.c of liquid.

$$a + x = b\,(1 + x) \qquad (i.e., W = G \times V) \qquad x = \frac{a - b}{b - 1}$$

(Figures representing wt. of 1 c.c. are same as figures for sp. gr.)

Examples.—(*a*) Acid, sp. gr. = 1.4 to be reduced to sp. gr.1.2.

$$x = \frac{1.4 - 1.2}{1.2 - 1} = \frac{.2}{.2} = 1$$

Ans. Equal volume of water.

---

*Specific gravity of liquids may be derived from Baumé scale by adding 133 to Baumé reading and dividing 143 by the sum. *Example:* Linseed oil marks 20° Baumé.

Then $\dfrac{143}{133 + 20} = 0.934 =$ sp. gr. referred to water as unity.

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(*b*) Sp. gr. of liquid to be brought from 1.85 to 1.25. How much water?

$$\frac{1.85 - 1.25}{1.25 - 1} = \frac{.60}{.25} = 2.4$$

Ans. For each *c.c.*, add 2.4 *c.c.* of water.

Proof:

Weight = 1.85 + 2.40 = 4.25
Volume = 1 + 2.40 = 3.40

$$\frac{W}{V} = \frac{4.25}{3.40} = 1.25 \text{ as required}$$

In the same way formula for liquid lighter than water to be made up to intermediate sp. gr. may be used.

The student will find that in any problem where the statement is not at once evident, *the general principle* $W = G \times V$ will solve it.

Problem XIV.—Specific gravity of a solid by the "bottle" method. This depends upon displacement of water, method slightly differing from the above.

This will first be illustrated in full. In practice a "tare" weight accompanies the "bottle," which is constructed to contain an even number of c.c. of water at about 16° C. Multiples of ten are best for the number of c.c.

Examples.—(*a*):

Bottle full of water, weight	32.026
Bottle with solid and filled with water, weight	63.526
Weight of the substance alone, "in air"	34.500

Solution.—Add together weight of water and bottle, and the substance itself, *weighed in air.*

	32.026
	34.500
Sum	66.526
Deduct weight of bottle with substance and filled with water.	63.526
Weight of water displaced is the remainder	3.000

We have now the needed data, viz: weight of the substance and weight of an equal volume of water.

As before: $\frac{W}{V} = G$. That is: $\frac{34.5}{3.00} = 11.5$ = sp. gr. of the solid.

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(For the weight of the water, 3 (grams) is also the number designating its volume in cubic centimeters, hence is taken as the "volume" of the water.)

Formulistically this is expressed as below:

$$\text{Specific gravity} = \frac{W}{(W + A) - K}$$

In which formula W = weight of substance taken; A = weight of bottle filled with water; K = weight of bottle and substance with bottle filled with water to the "mark."

Omissions of detail should be readily supplied by the student.

Since the apparatus provided for this method includes a "tare" weight for the bottle, the data are reduced in practice to weight in air, weight of the water, and weight of the substance + water remaining in the bottle—that is, the water originally present in the bottle *when full*, minus the volume of it displaced by the substance.

The operation then consists simply in weighing the substance, then placing it in the bottle, filling the latter with water and again weighing. Weight of water which fills the bottle by itself is a constant.

	Wt. of water.	Solid + water.	Solid in air.	G.
(*b*)	10	12.5	4.5	2.25
(*c*)	10	16.80	8.5	5.00
(*d*)	10	18.40	9.6	8.00
(*e*)	25	38.75	14.50	19.33
(*f*)	100	102.20	3.97	2.24
(*g*)	100	102.50	16.50	1.178
(*h*)	100	107.89	8.64	11.52
(*i*)	100	109.70	10.24	18.96
(*j*)	100	108.30	12.80	2.84
(*k*)	100	123.00	25.00	12.50
(*l*)	100	103.00	3.60	6.00

A great variety of cases may be based on the principle of specific gravity, and several will be found scattered among the miscellaneous problems. One special case is here annexed, with examples; all others are left to the device of the student.

Problem XV.—A mixture of two solids of known specific gravities being given, to deduce the respective weights of each, *given* the weight and specific gravity of the mixture.

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This is often called the problem of Archimedes, and was probably first solved by him. It is usually applied to the estimation of free gold in quartz.

Examples.—(*a*) General solution. Let x and y be the required weights of the two solids. Let a and b be their respective specific gravities (known). Let c = weight of the mixture and d = its specific gravity.

The easiest solution is by two simultaneous equations, viz:

$$x + y = c \quad \text{and} \quad \frac{x}{a} + \frac{y}{b} = \frac{c}{d}$$

Refer back to the general principle, $W = V \times G$, and its simple transpositions. The first equation reads "weights of the two substances equal weight of the mixture." The second reads "volumes of the two substances equal volume of the mixture."

$$x = \frac{ac(d - b)}{d(a - b)} \quad \text{and} \quad y = \frac{bc(a - d)}{d(a - b)}$$

In these as in other problems in specific gravity assume 1 c.c. as unit of volume and 1 gram as unit of weight. Call the two solids "*A*" and "*B*."

	Sp. gr. of *A*.	Sp. gr. of *B*.	Wt. of mix.	Sp. gr. mix.	Wt. of *A*.	Wt. of *B*.
(*b*)	19.3	2.66	10.0	6.0	6.45+	3.55
(*c*)	12.0	6.00	12.0	8.0	6.0	6.0
(*d*)	8.0	2.0	10.0	2.5	2.667	7.333
(*e*)	20.0	1.0	10.0	1.5	3.5+	6.5
(*f*)	20.0	2.5	10.0	7.0	7.347	2.653+

Miscellaneous Problems Involving Principles of Specific Gravity.

1. Sp. gr. of silver is 10.5. What is the weight of a cube of silver whose edge measures 3.5 centimeters?

Ans. 450.1875 grams.

2. Sp. gr. of iron is 8. An iron rod of square section is one meter long, section $1\frac{1}{2}$ cm. square. What is its weight?

Ans. 1800 grams.

3. Sp. gr. of copper is 8.8. A hollow sphere of copper *just floats* in water. Its wt. = 1 kilo. What is its volume? What is volume of the copper?

Ans. Vol. of sphere = 1 liter. Of copper = 0.1136+ liters. No allowance in (3) for air contained in the sphere.

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4. Sp. gr. of lead = 11.35. A sheet is $\frac{1}{8}$ of 1 centimeter thick, and one meter square. What is its weight?

Ans. 14187.5 grams, or $14\frac{1875}{10000}$ kilos.

5. Sp. gr. of zinc = 7. A rod of circular section is 1 cm. in diameter, and 1 meter long. What is its weight?

Solution:

$$R = 0.5. \quad R^2 = 0.25. \quad \pi R^2 = 0.7854$$
$$0.7854 \times 100 \times 7 = 549.78 \text{ grams.}$$

6. A kilometer of copper wire weighs 2000 kilograms. (Sp. gr. = 8.8.) What is the diameter of the wire?

Solution: Remember that $\frac{W}{G} = V$. Having ascertained volume of the wire in c.c., find area of the base of cylinder (*i.e.*, the wire itself), thence deduce its radius.

Ans. $R = 0.85054+$. (Double for diameter.)

7. Cubes of 6 and 15 cm. edge, respectively, have the same weight. The smaller has sp. gr. = 21, what is sp. gr. of the larger? *Ans.* 1.344 sp. gr.

8. A metallic cube weighs 39.304 grams. Sp. gr. = 8. What is length of its edge? *Ans.* 1.7 cm.

9. A sphere of quartz (sp. gr. = 2.5) weighs 19.9382 grams. What is its radius? *Ans.* 1.1 cm.

10. A hollow sphere of copper (sp. gr. = 8.9) is filled with water; the whole weighs two kilograms. Exterior diameter = 0.12 meter. What is thickness of the copper? What is its weight?

Solution:

$$R = 0.06. \quad \text{Surface} = 4\pi R^2 = 0.04523904. \quad \frac{R}{3} = 0.02.$$

$$V = 4\pi R^2 \times \frac{R}{3} = 0.0009047808 \text{ cubic meters}$$

(904.7808 cubic centimeters.)

Let x = weight of the copper. Let y = weight of the water.

$$x + y = 2000. \quad \frac{x}{8.9} + \frac{y}{1} = 904.7808.$$

Hence $x = 1233.855$ grams. $y = 766.145$ grams.

Then, $\frac{1233.855}{8.90} = 138.635$ cubic centimeters of copper.

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The surface has already been found, being 452.3904 square centimeters. Evidently cubic centimeters divided by square centimeters will give thickness of the metal.

$$\frac{138.635}{452.3904} = 0.306 \text{ centimeters} = \text{thickness of the copper.}$$

Weight of the copper, being value of x, has already been found.

11. Water at maximum density (4° C.) has sp. gr. = 1. Ice has sp. gr. 0.92. A liter of water at 4° becomes what volume of ice? (Sp. gr. is inversely as volume, for same weight.)

Ans. 1.087 liters.

12. An iceberg (sp. gr. 0.92) floats in sea water (sp. gr. 1.027.) What proportion of it will be above sea level?

Ans. 10.42 per cent.

13. Taking the above data for ice and sea water, how many cubic feet does an iceberg contain which shows 6000 cubic feet above water? *Ans.* 57,588.8 cu. ft.

14. Type metal contains: Lead, 70.00 per cent.; tin, 10.00 per cent.; antimony, 20.00 per cent. = 100.00 per cent. Take sp. gr. lead = 11.4. Sp. gr. tin = 7.3. Sp. gr. antimony = 6.7. Find the sp. gr. of the alloy, allowing neither expansion nor contraction. *Ans.* 7.53 sp. gr.

15. A liter of $POCl_3$ whose sp. gr. is 1.7 is deoxidized to PCl_3 whose sp. gr. is 1.6. What volume will the latter occupy?

NOTE.—Get the relative weight of the two—that is, from the known weight of the first, deduce stoichiometrically the weight of the second.

Then proceed with $V = \frac{W}{G}$ as in all similar cases.

Ans. 0.95175 liters.

16. A sphere of wood has 0.8 sp. gr. and 0.6 meter radius. What is its weight?

Find $\frac{4}{3}\pi R^3$. Multiply by 0.8

Ans. 723.82464 kilos.

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CALCULATION OF ANALYSES.

Analytical determinations are made in a variety of ways, of which only the more important need be epitomized.

1. By separation and weighing of the element itself, if solid or liquid, or, if gaseous, measuring its volume. (Cupellation of gold and silver. Copper by the battery, and other familiar cases.)

2. By the isolation, usually by precipitation, of a compound containing the element "sought." The compound being weighed, weight of the element is determined by its stoichiometric relation to the compound. This is the commonest of gravimetric methods. (*Example.*—AgCl, used for determination of either silver or chlorine.)

3. By weighing or otherwise estimating mass of some substance which, though not containing the "sought," has a definite relation to it. This is a mere variant of (2), principle being the same. (*Example.*—Having obtained ammonium chloroplatinate, $(NH_4)_2\ PtCl_6$, ignite it and weigh residual platinum, whose relation to nitrogen in the now destroyed compound gives us required weight of the latter. Or again, we destroy the identity of the well known "yellow precipitate," and titrate for molybdenum, although phosphorus is our "objective.")

4. By expelling the element "sought" or a compound of it, and absorbing this in a previously weighed tube containing an appropriate absorbent. (Organic determination of carbon and hydrogen. For the former, as CO_2, the "potash bulb." For the latter, as water, the "calcium chloride tube." Increase in weight of bulb or tube gives the desired datum.)

5. By loss. (*a*) The "sought" is expelled by ignition, and the residual matter gives its quantity by weighing and subtraction from original weight. (*b*) The "sought" is dissolved out of the portion taken for analysis, by either water or some proper solvent, and the residue weighed. (*c*) In gas analysis the whole volume of the mixed gases is passed through the solvent, and the loss of volume indicates volume (hence weight if desired) of one of the gases in the mixture.

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6. By some one of the countless methods of volumetric analysis. These depend one and all on stoichiometric relations, but have the great advantage, besides rapidity, of being workable by persons who have not the remotest idea of the reactions involved, as may be seen in numberless cases in the technical laboratories of large establishments.

There are a very few special estimations which might be thought to fall outside of these, but they are included in principle.

A word should be said, however, upon estimation by "difference" or "deficit." This is sometimes a mere matter of subtraction, but it may also become necessary to calculate a little, *e.g.*, in apportioning oxygen (not susceptible of direct estimation) to various bases found in the analysis. This leads to the subject, to be illustrated by examples, of what is called "adjudication," by which is meant in this connection the proper adjustment of elements found *to one another*, so as to show rational or probable *compounds* as the outcome of the analytical work. Here comes in the rule for "excess and deficiency" whose application is simple enough in fact, though often tedious. A perfect "adjudication" is rarely possible in practice.

In the following examples method of procedure is indicated in some, especially those requiring "adjudication" and in cases of indirect analysis. Very full explanations have been omitted, as the student should have a grasp of the subject from the previous cases of computation given.

It is better practice to work out a method by the aid of already acquired principles, than to have every step explained. The answers will serve to check errors.

It is necessary for the student in analytical chemistry to discriminate between true accuracy and what may be termed "pseudo-accuracy." The latter term may be applied to certain cases of useless figuring, and also to many cases of attempted refinement in weighing.

Before taking up either in illustration, we may put the general case thus: "Refinement in operation or calculation is thrown away, if it has been preceded by careless work."

Thus, to go through the operations for the determination of phosphorus, where the expected total is not over one-tenth of one per cent., working so carelessly that there is a probable

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error of not less than ten per cent. (*i.e.*, figuring percentage of error on the phosphorus obtained), that is, 0.01 per cent. of phosphorus; and then to weigh the resultant precipitate to the hundredth of a milligram, and gravely announce the result to the third decimal place, is "pseudo-accuracy" with a vengeance.

It is far from the intent of this paragraph to discourage careful weighing, or careful work at any point. But it is evident in the above case that any conclusion derived from the weighing, however careful, of the result, is not justified. Whatever value it has is derived from the actual operative work prior to the final weighing. The care taken in the latter cannot rectify the initial carelessness.

Useless refinement in "weighing in " is sometimes seen. The author remembers a striking instance, the chemist being a very skilful worker, who was making an analysis of refined lead, using the enormous quantity of one thousand grams. In order not to strain his balance, which was a small one, he weighed in ten portions of 100 grams each. In each portion he weighed with the utmost precision, trying to be certain that he did not miss total by the twentieth of a milligram, the limit of his balance.

The expected total impurity of the lead was less than two one-hundredths of one per cent.

Let us make the extreme supposition that the impurity was all in one element. Then suppose an error in weighing the original lead of *one-tenth of a gram.* This of course would be out of the question with the most ordinary care. But suppose it.

Then the error in determination of total impurity due to the misweighing will be $\frac{1}{100}$ of 1 per cent. of 0.2 gram. = 0.00002. Calculated in percentage of total weight taken it will be two millionths of one per cent.

But this very careful man weighed so carefully that he certainly did not miss the total by one milligram, or $\frac{1}{100}$ of our "supposition." His error on result then was under $\frac{2}{100,000,000}$ of one per cent., so that he unconsciously assumed that his balance was one thousand times more accurate than he knew it to be. "Accuracy" to this extent in this place is manifestly wasted.

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Every number denoting a physical measurement is limited in its accuracy by the physical limitations of that measurement, that is, of the instrument used and the capacity of the operator to use it to its limit.

For example, take 0.8 gram of a substance for analysis. We find the weight of one constituent to be 0.2349 gram. The percentage of the "found" is then:

$$\frac{0.2349 \times 100}{0.8} = 29.3625 \text{ per cent.}$$

Suppose, as is probable, that the accuracy of the balance is limited to 0.0001 or one-tenth of a milligram. That weight indicates 0.01 per cent. on a gram portion taken.

But here, *on a less portion* we assume, if we use the figured result of 29.3625, that we can carry the result to the ten thousandth of 1 per cent. The fallacy is in carrying an arithmetical operation beyond the possibilities of our powers of observation. *The last two figures have no real significance.* It is, in short, *arithmetically* true that .2349 is 29.3625 per cent. of 0.8. But it is not true that we can, by figuring until we get no remainder, make our balance perform the impossible. In going, in the percentage figure, *beyond the smallest indication of the balance*, we do not even know whether the next figure is positive or negative, because we are now splitting (theoretically) the minimum possible indication of the instrument.

Such procedures, then, we designate as "pseudo-accuracy." In the figure 29.3625 even the "6" in the second decimal place is subject to some doubt. How futile, then, to carry the division further.

It is not thought worth while to further illustrate this principle. What has been said will be quite enough for any student whose arithmetical sense has been developed.

No general discussion of the subject, "Calculation of Analyses," is necessary, for there is nothing in it which demands any new principle or method. The learner will soon perceive that, possibly with some trivial exceptions, every point has been already treated under some other head. We make a heading of it to indicate how previously given rules find here some practical applications.

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Examples.—(*a*) One gram of coal yields 0.07 $BaSO_4$, what per cent. of sulphur does it contain?

$$0.1373 \times 0.07 = 0.0096. \qquad \textit{Ans.}\ 0.96 \text{ per cent.}$$

If the student is not already used to "translating" weights (*i.e.*, fractions of a gram) into percentages he will do well to start at this problem. The portion taken being one gram, 100 per cent. is represented by one gram, *i.e.*, by 1.0. Analyses, however, are always written with *percentages in whole numbers and decimal fractions of same.* Having taken 1 gram for analysis, one per cent. appears in the figures (*weights*) as 0.01. Twelve and a half per cent. would be 0.1250. Half of one per cent. would be 0.0050.

Having the Weight, Expressed in Grams, Move the Decimal Point Two Places to the Right to Express Percentage Direct, i.e., Parts in 100.

Many a student has learned this in five minutes. Few laboratory instructors but can bear me out in the assertion that there are others who are liable to stumble over it for weeks. It is not a "function" of the learner's natural power of apprehension, but of the way (usually exceedingly bad) in which he has been taught arithmetic. Most high-school graduates are hazy on the two most used of all principles after the elements, *i.e.*, decimals and proportion.

(*b*) We expel from a substance (1 gram) 284 c.c. (0.284 liter) of carbon dioxide (CO_2). What per cent. by weight of it in the substance (0° and 760 mm.)? *Ans.* 44 per cent.

(*c*) A mixture of the chloride and bromide of silver weighs 1 gram.

$$AgBr + Cl = AgCl + Br$$

We convert it all into chloride by the reaction shown in the equation. The chloride now weighs 0.92 gram. *Find weights of chlorine and bromine. Do not use the atomic weight of silver* in the calculation. (Use approximate weights 35.5 and 80.)

Solution.—The loss of weight is due to the substitution of chlorine for bromine. Hence it is proportional to the difference of these two in atomic weights. Loss = 0.08 gram. Diff. in at. wts., 80 − 35.5 = 44.5.

Then:

Diff. in at. wts.	:	At. wt. Br	=	Loss in wt.	:	Wt. of Br
44.5	:	80	=	0.08	:	0.1438

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We may now cupel the chloride and weigh the silver, whence the chlorine by subtraction, fulfilling the requirement not to use the at. wt. of silver.

(*d*) A mineral (1 gram) yields a mixture of the chlorides of potassium and sodium which weighs 0.3687 gram. From this is afterward precipitated potassium salt K_2PtCl_6 0.4240 gram. What are the percentages of potassium and sodium? (Method indicated without operations.)

1. Compute potassium from the platinum salt.* 2. Compute weight of potassium chloride from the element. 3. Subtract this weight from the original mixture. 4. Calculate sodium from its chloride.

Ans. Potassium 6.83 per cent. Sodium 9.36 per cent.

(*e*) A crucible containing copper weighs 12.234, but when the copper is converted into cupric oxide (CuO) it weighs 12.348. What was weight of copper? *Ans.* 0.4517 gram.

(*f*) Five (5) grams of hematite yield the following precipitates:

For sulphur—$BaSO_4$, 0.0700; for P_2O_5, $Mg_2P_2O_7$, 0.0400; for Fe_2O_3, iron (volumet.), 3.15; for SiO_2, SiO_2, 0.4648.

Find percentages of sulphur, ferric oxide, phosphoric anhydride, silica. Multiply by factors from table, divide by 5 and move decimal point. (Iron = 56)

Answers. S. = 0.192. P_2O_5 = 0.5103 per cent.
Fe_2O_3 = 90.00. SiO_2 = 9.296 per cent.

(*g*) Mixture of KCl and NaCl weighs "*a*." Mixture of K_2SO_4 and Na_2SO_4 wt. "*b*." Find percentages of potassium and sodium. Let x = K, and y = Na.

$$x + \frac{35.5}{39}x + y + \frac{35.5}{23}y = a. \qquad (K = 39.\ \ Na = 23).$$

$$x + \frac{48}{39}x + y + \frac{48}{23}y = b. \qquad (\text{Fractions} \div 2, \text{ num. and den.})$$

In these fractions, the ratios between the atomic weights of the metals and the anions are shown. Let the student figure out the detail. Numerical example is annexed.

(*g*) Numerical example. Let "*a*" = 0.1328 and "*b*" = 0.1580.

* It is quite as easy, however, if only KCl is sought, to use factor which gives it directly from Pt. See table of "Chemical factors."

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As before, let x = potassium and y = sodium. We shall then find: Potassium = 0.039 and sodium = 0.023.

If we should put x = KCl, and y = NaCl, we have:

$$x + y = 0.1328, \text{ and } \frac{87}{74.4}x + \frac{71}{58.4}y = 0.158$$

(*h*) We take four portions of pig iron for analysis, viz: 5 grams for sulphur, 5 for phosphorus, 3 for carbon and 1 for silicon. (Use factors.)

Weights of the various precipitates with answers opposite.

$Mg_2P_2O_7$	0.0400	P = 0.223 per cent.
$BaSO_4$	0.02335	S = 0.065 per cent.
SiO_2	0.0380	Si = 1.783 per cent.
CO_2	0.2200	C = 2.000 per cent.

(*i*) An ore contains the following constituents only, viz: silica, pyrite (FeS_2), zinc sulphide and lead sulphide. Its analysis by elements gave the following, (portion taken for analysis 1.5 *gram* in each determination):

For silica	SiO_2	= 0.5892 gram.
For iron	Fe_2O_3	= 0.1599 gram.
For lead	$PbSO_4$	= 0.6039 gram.
For zinc	ZnO	= 0.1620 gram.
For sulphur	$BaSO_4$	= 1.8639 gram.

Calculate this analysis and sum (1) by elements (except silica which goes in as SiO_2); (2) by compounds as given in the statement.

BY ELEMENTS.		BY COMPOUNDS.	
Silica	39.28 per cent.	Silica	39.28 per cent.
Iron	7.46 per cent.	Iron di-sulphide	16.03 per cent.
Lead	27.50 per cent.	Lead sulphide	31.76 per cent.
Zinc	8.69 per cent.	Zinc sulphide	12.93 per cent.
Sulphur	17.07 per cent.		
Total	100.00 per cent.	Total	100.00 per cent.

Requirements similar to this are very common, though such perfect summations are not usual. This is a mere "set up" case.

Methods of procedure (not operations) are here given. They are much the same in all cases of mineral, matte or slag analysis, where there is any "adjudication" to arrange.

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Calculate how much sulphur is required for all of the zinc. Subtract from total sulphur and add to zinc, making zinc sulphide (ZnS).

Find sulphur needed for all of the lead. Subtract it from the sulphur left after allowing for zinc. Add to lead, making PbS.

Find sulphur needed for all of the iron. In this particular case it "balances" exactly. If, however, the sulphur left after allowing for zinc and lead had been too small for the iron, we should put it all into pyrite (FeS_2) and then, taking *the iron left over*, calculate that to oxide.

Other cases of adjudication, residual quantities and excess will be found in the following examples.

(*j*) One gram of organic matter has its nitrogen determined as gas, by measurement of volume at 0° and 760 mm. Volume, 100 c.c. (0.100 liter). What per cent. of nitrogen?

Ans. 12.5 per cent.

(*k*) In 1 gram of organic matter, we convert nitrogen into ammonia which is absorbed into HCl, forming NH_4Cl. Addition of $PtCl_4$ reacts thus:

$$2NH_4Cl + PtCl_4 = (NH_4)_2PtCl_6$$

This precipitate is ignited, which destroys it, leaving only the platinum behind.

Weight of the metallic platinum = 0.64 gram. What per cent. of nitrogen? *Ans.* 9.20 per cent.

(*l*) A fertilizer contains the three forms of calcium phosphate, known as "soluble," "reverted," and "insoluble." (These are taken out by proper solvents and phosphoric acid determined separately in each portion.)

Results in actual P_2O_5 percentages are here given as derived from each form. Calculate the analysis, *i.e.*, state what is the percentage of *each form of calcium phosphate.* (The percentages are on the total of the fertilizer in every case.) Find also per cent. of total CaO with P_2O_5.

From $CaH_4(PO_4)_2$ ..... 10.0 per cent. of P_2O_5.
From $CaHPO_4$ ..... 3.0 per cent. of P_2O_5.
From $Ca_3(PO_4)_2$ ..... 8.0 per cent. of P_2O_5.

Look sharp in calculating the middle substance, $CaHPO_4$.

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Under what form of error does this fall, as a danger which has been warned against? Use Ca = 40.0 at. wt.

Answers. $CaH_4(PO_4)_2$ .16.48 per cent.
$CaHPO_4$.....5.75 per cent.
$Ca_3(PO_4)_2$...17.46 per cent. Total CaO, 16.56 per cent.

(*m*) In analysis of a mixture of KCl and NaCl we find (1 gram taken):

Impurities..... 0.069 gram.
(K, Na) Cl..... 0.931 gram. Total, 1.000 gram.

From the precipitate AgCl the *total chlorine* is found to weigh 0.497.

Find weights of the potassium and sodium—also of their chlorides separately. (Note that 0.931 − 0.497 = 0.434). Let x = Na, and y = K.

$$x + y = 0.434. \qquad \text{Also, } x + \frac{35.5}{23}x + y + \frac{35.5}{39}y = 0.931$$

Whence:

x = Na = 0.161 NaCl = 0.4095
y = K = 0.273 KCl = 0.5215 Total, 0.9310.

(*n*) Analysis of common salt. One gram taken, which contains, beside NaCl, calcium sulphate, magnesium chloride and water. Weights as follows:

CaO = 0.0062. $BaSO_4$ = 0.0258. $Mg_2P_2O_7$ = 0.0111. AgCl = 2.3938

CaO needs no calculation except adjustment to SO_3.

$BaSO_4$ calculated to SO_3, .0258 × .3429 = 0.0088 = wt. of SO_3
0.0062 : 0.088 = 56 : 80. That is, the CaO and SO_3 just "match."

The magnesium similarly calculated gives $MgCl_2$ as follows:

$Mg_2P_2O_7$: $2MgCl_2$ (Why $2MgCl_2$ instead of $MgCl_2$?)
222.72 : 190.52 = 0.0111 : 0.0095 = wt. of $MgCl_2$

Note that it is not necessary to figure Mg or MgO first. We compute to $MgCl_2$ directly.

It is necessary, however, to figure the chlorine out from this $MgCl_2$ so that little is saved by the direct computation. We find 0.0070 as the weight of its chlorine. From weight of AgCl we find total of 0.5918 chlorine, from which we subtract that called for by magnesium.

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0.5918 − 0.0070 = 0.5848 = wt. of chlorine combined with sodium.

From this we get the NaCl simply enough:

$$\frac{.5848}{.606} = 0.965 \text{ gram, or } 96.50 \text{ per cent.}$$

(Since NaCl has 60.60 per cent. of chlorine.)

Ignition at gentle heat causes the salt to lose 0.0090 on 1 gram taken.

Summation:

(0.62 CaO + 0.88 SO_3 = 1.50 per cent. $CaSO_4$)

Sodium chloride (NaCl)	96.50 per cent.
Calcium sulphate ($CaSO_4$)	1.50 per cent.
Magnesium chloride ($MgCl_2$)	0.95 per cent.
Water	0.90 per cent.
Summation	99.85 per cent.
Loss or deficit	0.15 per cent.
	100.00 per cent.

(*o*) A slightly oxidized ore contains silica, iron di-sulphide (pyrite) zinc sulphide and some iron oxide (ferric oxide). Weights from 1 gram: Silica 0.4958. For total iron, Fe_2O_3 = 0.2224. For zinc, ZnO = 0.1456. For sulphur, $BaSO_4$ = 1.6630.

Compute by assuming all of the zinc present as ZnS. Then "adjudicate" by letting all remaining sulphur go to iron as FeS_2; finally compute any iron left over as Fe_2O_3. Begin by computing per cents. in toto:

The $BaSO_4$ gives as per cent. of total sulphur	22.83
The Fe_2O_3 gives as per cent. of total iron	15.56
The ZnO gives as per cent. of total zinc	11.70

Now adjust according to the scheme given above:

11.7 zinc requires 5.74 sulphur. This gives 17.44 per cent. ZnS.

22.83 sulphur − 5.74 sulphur = 17.09 sulphur remaining for iron.

According to the formula FeS_2, 17.09 S_2 requires 14.9 Fe. 31.99 per cent. FeS_2.

15.56 Fe − 14.9 Fe = 0.66 Fe. ("Residual" iron.) 0.66 Fe corresponds to 0.94 per cent. Fe_2O_3.

The silica requires no computation except moving the decimal.

Described in ordinary language the process is this:

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"Take out all the zinc as zinc sulphide. Subtract the required sulphur from total sulphur, then take out as much pyrite (FeS_2) as the sulphur allows you. Finding some iron left over, adjust this to as much oxygen as it will carry as Fe_2O_3. Add in the silica as weighed."

Summation:

Silica	49.58 per cent.
ZnS	17.44 per cent.
FeS_2	31.99 per cent.
Fe_2O_3	0.94 per cent.
	99.95 per cent.
Loss	0.05 per cent.

(*p*) In the analysis of a fertilizer compound, we get from 1 gram portions: For NH_3; Pt = 0.4200. For K_2O; KCl = 0.0220. For P_2O_5; $Mg_2P_2O_7$ = 0.6560. For SO; BaS_2O_4 = 0.0466. Find percentages of the required constituents.

Answers: NH_3.....7.346 per cent. P_2O_5....41.96 per cent.
K_2O.....1.390 per cent. SO_3.....1.600 per cent.

(*q*) In an iron ore, which contains both FeO and Fe_2O_3 all the elements are determined, iron being estimated as all Fe_2O_3. Metallic iron = 65.10 and summation is 100.7 per cent. Assuming that this is absolutely correct as to operations, find percentages of FeO and Fe_2O_3. Also what per cent. of iron in the FeO and what in the Fe_2O_3? (Take iron as 56. This makes factor to pass from Fe_2O_3 to Fe = 0.7.)

Solution.—All we have to "go on" is the excess of 0.7 which arises from estimating all the iron as existing in the form of Fe_2O_3, whereas some of it is present as FeO (magnetite, which is written Fe_3O_4, *i.e.*, Fe_2O_3 + FeO). Results, not operations, are given. The student should remember that in the comparison of FeO and Fe_2O_3 we must consider FeO as Fe_2O_3 or 2FeO.

Answers: FeO = 6.30. Its iron = 4.90 per cent.
Fe_2O_3 = 86.00. Its iron = 60.20 per cent.

(*r*) One gram of anthracene is analyzed. Its carbon weighed as CO_2 gives 3.4591 grams. Its hydrogen *weighed as water* gives 0.5058 gram.

Ans. Carbon 94.34 per cent. Hydrogen 5.66 per cent.

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Deduce formula from this analysis. *Ans.* C_7H_5. But as molecular weight is about 178 the trial formula must be doubled, *i.e.*, $C_{14}H_{10}$.

(*s*) A sample of sodium bicarbonate contains both Na_2CO_3 and $NaHCO_3$. Its total carbon dioxide (CO_2) is determined as 45 per cent. and its total sodium as Na_2O = 32 per cent. *Required*, percentages of the two forms as above, of sodium carbonate. It is of course necessary to assume that no other forms or compounds of sodium are present. Let $x = Na_2CO_3$ and $y = NaHCO_3$. (Use Na = 23 and H = 1.)

$$\frac{CO_2}{Na_2CO_3}\,x + \frac{CO_2}{NaHCO_3}\,y = 45$$

$$\frac{Na_2O}{Na_2CO_3}\,x + \frac{Na_2O}{2NaHCO_3}\,y = 32$$

Substitute values in the formulæ, *i.e.*, molecular weights. The remainder of the process is omitted, except as to the suggestion that it will be found rather easier to solve for "*y*" and then proceed with the other deductions. Get per cent. of Na_2O in the carbonate first determined, etc.

Answers. $NaHCO_3$ = 85.11 per cent. Na_2CO_3 = 1.01 per cent.

(*t*) A mixture of $CaSO_4$ and $CaCO_3$ gives: CaO, 11.2 grams. SO_3, 8.0 grams. Find weights of $CaSO_4$, $CaCO_3$, and CO_2.

Answers. $CaSO_4$ = 13.60 grams; $CaCO_3$ = 10.00 grams; CO_2 = 4.40 grams.

(*u*) Being about to determine calcium as CaO, I ignite it in a platinum crucible, and then find I have forgotten to weigh the latter. However, I weigh the whole, then add sulphuric acid and ignite again, converting the CaO into $CaSO_4$. The gain is 0.4 gram. What was weight of the CaO? (Use approximate weights, Ca, 40; S, 32.) *Ans.* 0.28 gram.

(*v*) A mixture of the chloride and bromide of silver weighs 0.75 gram. The silver in same weighs 0.50 gram. Find the percentages of bromine and chlorine. Take silver 108, chlorine 35.5, bromine 80, atomic weights.

$$Ag : AgCl = Ag : AgCl$$
$$108 : 143.5 = .50 : .6643$$

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That is, if all were AgCl the total would weigh only .6643 instead of .7500. The excess, which equals .0857, is due to the replacement of part of the (assumed) chlorine by bromine.

Difference between atomic wts. (Br — Cl) is 44.5. Hence:

$$44.5 : 80 = .0857 : 0.154. \quad \text{Weight of bromine } 0.154$$
$$\text{Also, } 0.75 - (.5 + .154) = 0.096 = \text{chlorine}$$

(*w*) From one gram of iron we expel the sulphur as H_2S and with the latter we precipitate 24 milligrams of lead sulphide (PbS). What per cent. of sulphur in the iron?

Ans. 0.321 per cent.

(*x*) $MnO_2 + 2FeCl_2 + 4HCl = MnCl_2 + Fe_2Cl_6 + 2H_2O$

0.5 metallic iron dissolved in the acid, also 1 gram of the manganese ore. We now find 0.285 iron by titration. What was percentage of MnO_2 in the ore. (We assume that the titration was upon the ferrous salt remaining.)

Ans.—The .215 remaining indicates the Fe_2Cl_6 of the equation. Final calculation left to the student.

Ans. 16.7 per cent. MnO_2 in the ore.

(*y*) Sulphur from 1 gram of substance is evolved as H_2S, which measures 20 c.c., normal conditions. Find per cent. of sulphur. (Part of operation omitted.)

$$22.4 : 34 = 0.02 : 0.03036. \qquad \textit{Ans.}\ 2.857 \text{ per cent. sulphur.}$$

(*z*) Spring water analysis. One liter gave 147.94 parts per 100,000, or 1.4794 grams, of solid matter. Silica weighed 0.0074. Al_2O_3, 0.0015, $FeCO_3$, 0.0014, the latter calculated from titration for iron.

Other elements gave precipitates weighing as follows:

For SO_3 ..... $BaSO_4$	0.4768
For CaO ..... $CaSO_4$	0.5497
For MgO ..... $Mg_2P_2O_7$	0.3568
For K_2O ..... K_2PtCl_6	0.1708
Alkalies as chlorides weighed	0.7644
Chlorine determined by silver, weight..	0.1400 (Cl not AgCl)

All other salts are carbonates. Calculate sodium by difference, and sum up the analysis.

First assign all the SO_3 to CaO. Excess of CaO to carbonate.

All the chlorine to magnesium. Excess of the latter to carbonate.

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Potassium to carbonate. All of the calculated sodium to carbonate.

Silica	0.74	Potassium carbonate	4.87
Alumina	0.15	Calcium sulphate	27.90
Ferrous carbonate	0.14	Magnesium chloride	18.73
Calcium carbonate	19.80	Parts per 100,000	147.54
Magnesium carbonate	10.57	Loss	.40
Sodium carbonate	64.64		147.94

The above is an actual case. It is left as originally computed by atomic weights of 1907. Differences, if computed by 1911 factors, are exceedingly trivial.

Analysis of Mineral Waters.

Statements of mineral water analysis are not made on a strict "per cent." basis. A common method has been to give the "grains per gallon" of solid constituents. It is, however, becoming more usual to state "parts in 100,000" or "parts in 1,000,000."

Taking one liter of water for analysis each centigram is evidently "one part per 100,000" and each milligram is "one part per million."

United States gallon contains 58,318 grains of water. British Imperial gallon contains 70,000 grains (one lb. avdp.). Using metric weights and measures we may construct "assay gallons." If the estimation is to be made directly in "grains to gallon" take *as many centigrams* (by measure) *of the water as there are grains in the gallon.* This applies to either U. S. or British gallon. As the specific gravity of the water cuts no figure, we state *weight* of constituents per *volume* of water.

For statement in U. S. gallons take 0.58318 liter. For statement in Imperial gallons take 0.7 liter.

Then each centigram "found" of solid matter equals "one grain to gallon."

To calculate from one system of expression to another, use the following conversion factors:

Grains per U. S. gallon $\times$ 17.147 = parts per million.
Grains per Imperial gallon $\times$ 14.285 = parts per million.

Parts per million $\times$ .058318 = grains per U. S. gallon.
Parts per million $\times$ .07 = grains per Imperial gallon.

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ASSAY WEIGHTS AND CALCULATIONS.

By an "assay" as distinguished from an "analysis" is usually understood the determination of a single constituent instead of the determination and summation of all the elements of an ore or other material.

We here confine the term to assays for the precious metals.

Assay reports in the United States are invariably made, so far as gold and silver are concerned, so as to return "ounces per ton."

The "Assay Ton," first devised by Dr. Chandler of the Columbia School of Mines, is now in use to the exclusion of all other units for "weighing in" of the assay charge. It is based upon the fact that a short ton (2,000 lbs.) contains 29,166⅔ troy ounces. Ore being always weighed in short tons, and the precious metals as invariably in "Troy," the convenience of a weight whose use dispenses with most of the after calculations is evident at sight.

The device, then, is simply the adoption of a miniature ton in which, or in some multiple or sub-multiple of which, the ore is weighed. *In this miniature ton, the troy ounce is represented by the milligram.*

Hence the "ton" itself contains 29,166⅔ milligrams.

If the "ton," as is usually the case, be considered too large a weight, some sub-multiple is taken. If a fifth of a "ton" is taken the results are multiplied by 5. If a tenth, by 10, etc.

Normally, however, with one "assay ton" as the ore-weight, it is obvious that *each milligram of metal found indicates one ounce to the ton.*

The "Ore and Scales" Problem.

It sometimes happens that an ore contains particles ("scales") of metal which cannot well be reduced to powder. If these "scales" are at all large, the difficulty of getting an average "pulp" for assay is serious.

Suppose, for an example, that we have a somewhat low-grade gold ore for assay, which nevertheless holds occasional particles of free gold. Say the bottled sample for assay contains one particle of free gold whose weight is *one milligram.* The assayer will probably take 0.1 assay ton for the assay. Then one milli-

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gram indicates *ten ounces* to the ton. In taking out his weight of ore he may or may not happen to include the "nugget," and the difference in result, being something over two hundred dollars to the ton, would be quite startling!

No device entirely obviates the uncertainty of assay results on very high grade ores, when free metal is present. Resampling and repetition of assays accompanied with more or less squabbling and recrimination, is a common experience.

The "ore and scales" method, sometimes called "pulp and scales," aims to avoid some of the uncertainty by screening out as much as possible of the metallic "scales." Then the ore and the scales are separately assayed.

No demonstration is needed to show that it is of primary importance that the ratio of the scales to the whole amount screened should be known.

It is also evident that only the ore which has passed through the screen should be assayed, then the two assays are combined as described below.

VALUATION OF AN ORE BY THE "ORE AND SCALES" METHOD.

Let "A" be the assay value of the sample.

"a" = charge of ore *in assay tons.*

"b" = weight of the yield, *in milligrams.*

Then:

$$A = \frac{b}{a} \text{ (e.g., } a = 1,\ b = 6, \text{ then } A = 6 \text{ ounces to ton)}$$

But if the ore be weighed *in grams,* whose number = "c," then:

$$A = \frac{29166\ b}{c}$$

In an assay containing both ore and scales, separate by a fine screen, and weigh each portion. Then:

Let x = weight of pulp, and y = weight of scales (in grams).

z = assay of pulp (*oz. to ton*) for silver.

z' = assay of pulp for gold.

q = grams of silver in the scales, and q' ditto for gold in scales.

Note that we take the *whole quantity* of the scales for assay, be the same more or less, assuming that it is not possible to "sample" them fairly.

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Of the ore we *take* whatever quantity is supposed to be requisite, in the usual manner for assaying, *i.e.*, in "ton" weights. But in applying the formula the *whole quantity* of ore screened must be reckoned with, of course, else the ratio of scales to screened ore is lost, and with it the entire calculation.

$$a = \frac{x+y}{29166} \qquad b = \frac{xz}{29166} + q \text{ (for silver).}$$

$$a = \frac{x+y}{29166} \qquad b = \frac{xz'}{29166} + q' \text{ (for gold).}$$

Substitute these values of a and b in the first equation, $A = \frac{b}{a}$, we have:

$$A = \frac{xz + 29166q}{x+y} \text{ silver.} \qquad A' = \frac{xz' + 29166q'}{x+y} \text{ gold.}$$

We can use the formula for one metal only, or for two. Ordinarily, both silver and gold are sought in the same sample.

Example 1.—Weight of "pulp" 800 grams; of "scales" 40 grams. Assay of pulp: gold = 1.2, and silver = 108 oz. to ton. Scales, assayed "in toto" contain 0.05 gram gold, and 30.56 grams silver.

$x = 800.$ $y = 40.$ $z = 108.$ $z' = 1.2.$ $q = 30.56.$ $q' = 0.05$

Then, $xz = 86{,}400$ and $x + y = 840.$ $29{,}166q = 891{,}312.96$

$$\text{Silver} = \frac{86{,}400 + 891{,}312.96}{840} = 1163.944 \text{ ounces to ton.}$$

Also, $xz' = 960$ and $29{,}166q' = 1458.30.$

$$\text{Gold} = \frac{960 + 1458.3}{840} = 2.8789 \text{ ounces to ton.}$$

Example 2.—Weight of pulp 987 grams. Of scales 1.41 grams. Assay of pulp: silver, 67 oz. to ton; gold, 0.2 oz. to ton. Scales contain: silver, 1.2 gram; gold, 0.1 gram.

$x = 987.$ $y = 1.41.$ $z = 67.$ $z' = 0.2.$ $q = 1.2.$ $q' = 0.1$

Ans. Silver 102.3 oz. to ton; gold 3.15 oz. to ton.

Example 3 (one metal).—Pulp 1 kilogram. Scales 2.5 grams. Assay of pulp 150 oz. to ton. Metal in scales 2.4 grams.

$x = 1000.$ $y = 2.5.$ $z = 150.$ $q = 2.4$

$xz = 150{,}000$ $\quad x + y = 1002.5$

$29{,}166 \times 2.4 = 69{,}998.4$

Ans. 219.45 oz. to ton.

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To Reduce Assays Giving Ounces to Ton, to Percentage Basis, or the Reverse.—Since there are 29,166 ounces troy in a ton, one-hundredth of that number, viz: 291.66, is one per cent. That is, an ore containing one per cent. of metal yields 291.66 oz. to ton by assay.

Hence the very simple rules:—Given the percentage, to find ounces to ton, multiply the percentage by 291.66. Given ounces per ton, to find percentage, divide number of ounces by 291.66.

If a multiple of the assay ton is taken for assay, *divide* result in milligrams by the number of tons taken, to obtain ounces to ton.

If a fraction of assay ton were taken, represented by a vulgar fraction, then *multiply* result in milligrams by the denominator of the fraction. If represented decimally, divide by the decimal fraction.

Examples in assay of irregular weights.

(4) 10 grams ore yield silver 0.05, and gold 0.001 gram. Find "assay." *Ans.* Silver, 145.83; gold, 2.916 oz. to ton.

(5) 13 grams ore. Silver, 0.045. Gold, 0.002. Find "assay." *Ans.* Silver, 100.91; gold, 4.48 oz. to ton.

Other examples will be found in the miscellaneous exercises.

Some Relations of Weight to Value in the Precious Metals.

One Troy ounce of gold, U. S. coinage value, is worth $20.6718.

One Troy ounce of silver, U. S. coinage value, is worth $1.2929.

One short ton* (2000 lbs. avdp.) of gold is worth $602,927.50 (six hundred and two thousand nine hundred and twenty-seven $\frac{50}{100}$ dollars).

One short ton* of silver is worth (coinage value) $37,709.58 (thirty-seven thousand seven hundred and nine $\frac{58}{100}$ dollars.)

One Troy pound of gold is worth $248.0616.

One Troy pound of silver is worth $15.5148.

One grain of gold is worth 4.306625 cents.

One grain of silver is worth 0.2693 cent.

One gram of gold is worth $0.66461.

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* A ton of gold would make a cube of 14¼ inches edge. A ton of silver would make a cube of 17¼ inches edge.

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One milligram of gold is worth $0.00066461 or 0.066461 of one cent.

One gram of silver is worth $0.041567.

One milligram of silver is worth $0.000041567 or 0.0041567 of one cent.

One dollar's worth of gold weighs 23.22 grains.

One dollar's worth of silver weighs 371.258 grains.

One gold dollar, 900 fine, weighs 25.8 grains.

One silver dollar, 900 fine, weighs 412.5 grains.

By "fine" gold is meant simply gold chemically pure. The figures above all refer to "fine" gold.

By "parts fine" is meant the number of parts in one thousand which a given coin or bar may contain of "fine" gold.

Thus a gold bar which is said to be 820 fine contains $\frac{820}{1000}$ of gold and $\frac{180}{1000}$ of some other metal. United States gold coin is always "900 fine."

To find the value per ounce of a bar whose fineness has been determined by assay we multiply $20.6718 by the fineness, the latter being taken as a fraction, *e.g.*, if we have found "920 fine," we multiply by .920.

Then the weight of the bar, in ounces and decimals, is multiplied by the value per ounce.

A "carat" is merely another division of the fineness of a mass of gold. A "carat" in gold valuation is not a weight, but a fraction—one twenty-fourth of the total, whatever that may be.

Eighteen carat gold is simply gold of which $\frac{18}{24}$ *is* gold. Translated into mint language, it would be stated as "750 fine."

Carats, with corresponding fineness and value per ounce. 1—24.

Carats.	Fine.	Value.	Carats.	Fine.	Value.
1	41.66	$0.86	13	541.66	$11.19
2	83.33	1.72	14	583.33	12.05
3	125.00	2.58	15	625.00	12.92
4	166.66	3.45	16	666.66	13.78
5	208.33	4.31	17	708.33	14.64
6	250.00	5.17	18	750.00	15.50
7	291.66	6.03	19	791.66	16.36
8	333.33	6.89	20	833.33	17.22
9	375.00	7.74	21	875.00	18.08
10	416.66	8.60	22	916.66	18.94
11	458.33	9.46	23	958.33	19.80
12	500.00	10.33	24	1000.00	20.67

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MEXICAN ASSAY RETURNS.

Mexico uses the metric system, and assays of ores for the precious metals are reported in grams to the metric ton (tonne).

As there are one million grams in a metric ton, one gram to the "tonne" is one millionth, or one ten-thousandth of one per cent.

Since one hundred per cent. in the Mexican system equals 1,000,000 grams, and one hundred per cent. in the United States system equals 29,167 ounces, we have:

$$\frac{1{,}000{,}000}{29{,}167} = 34.285$$

That is, any number of grams to tonne is 34.285 times corresponding "ounces to ton."

Hence, *given grams to tonne* in a Mexican report, *to find ounces to ton* in the United States system:

"Divide number of grams by 34.285."

We may also multiply by the reciprocal:

$$\frac{1}{34.285} = 0.029167$$

The latter has the advantage of presenting the same significant figures as the familiar number denoting ounces Troy in a ton, or milligrams in an assay ton.

To pass from ounces to grams it is only necessary to reverse the rule, using 34.285 as multiplier or 0.029167 as divisor.

Example.—Grams of metal to "tonne," 3679; how many "ounces to ton"? *Ans.* 107.3.

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VOLUMETRIC ANALYSIS

By "Volumetric" analysis is meant analysis by means of solutions of certain reagents, whose exact chemical equivalence *per liter* (or other definite volume) is known.

The analytical operation is known as "titration."

The reagent is dropped from a graduated vessel (usually a burette) into a solution of the substance which is being estimated.*

It is necessary that some visible "end point" should mark the completion of the reaction. This "end point" may be the appearance of a color, or the vanishing of a color. It may be the cessation of the formation of a precipitate, or (as in acid-alkaline interaction) a change of color instead of appearance or disappearance. Finally, there may be no sufficient change visible in the solution under examination to warrant the designation of "end point" but the solution may be tested by the withdrawal of a small portion (on the end of a rod), which drop is then tested by another reagent, usually on a "spot plate" made for the express purpose of such tests.

Example.—In the titration of a ferrous solution by potassium bichromate, the true "end point," *i.e.*, the entire transition of the ferrous salt into the ferric form, cannot be recognized in the solution itself. When it is suspected that the "end" is near, a drop of the solution is withdrawn and touched to a drop of testing solution—"ferricyanide." Since ferrous salts give a blue color with potassium ferricyanide and ferric salts do not, the gradual lessening of the blue color in successive tests indicates the approach of the "end," and the failure to produce any color marks the true "end point."

Other changes may be exemplified in the disappearance of the rich purple of "permanganate" in the iron and many other tests. The change of litmus from red to blue or vice

* In a few cases this may be reversed, the solution under examination being dropped into a previously measured amount of the reagent. The chemical principle is not affected. A few examples will be given of this procedure.

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versa, the appearance of starch-iodine blue when the first excess of iodine has been liberated, and several others are familiar matters to the laboratory.

This brief indication of the ordinary procedure in volumetric analysis is all that can be said as to its practice. We are concerned entirely with its arithmetic, and shall give only such comments upon methods as are needed to explain the application of the proper calculations.

First, the student should understand that the reactions commonly encountered in volumetric analysis are interpreted by equations in exactly the same fashion as in all cases (viz: a great majority of all chemical reactions) where equations can be used at all.

Example:

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

This expresses the neutralization of ammonia by addition of sulphuric acid (or the reverse). If litmus had been added to the ammonia, the color at the moment the least excess of acid was present would "indicate" by turning to red. At this moment the equation is exactly satisfied.

Example (starch added as indicator):

$$I_2 + H_2S = 2HI + S$$

This equation may be satisfied by the addition of the iodine to the hydric sulphide or the reverse. If starch has been added in small but indefinite quantity, the color will appear in the first case or disappear in the last, marking in either case the completion of the equation.

We have already gone a little further into "operative" volumetric than was intended, the object being to impress upon the student the fundamental principle that the "end point" is just as much within the sphere of the chemical equation as in any case in gravimetric analysis. There are, in fact, cases in which even the operations themselves are *chemically* identical in volumetric and gravimetric.

Example:

$$AgNO_3 + NaCl = AgCl + NaNO_3$$

If this were a gravimetric case the silver chloride would be separated out and weighed, if volumetric the exact point

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of precipitation would be recognized by some suitable means. Precisely the same chemical reaction is involved in either case.

Volumetric solutions may be roughly classed under three heads. No matter how a solution is "made up," however, its relation to the substance with which it reacts is the same, the differences being merely matters of figures. To illustrate by arithmetic, the ratio of three to seven is the same as the ratio of one hundred and twenty-three to two hundred and eighty-seven. The first is rather easier to handle, and solutions bearing relations expressed by simple numbers are easier to figure on than more complex ones. As a safeguard against error, it is strongly recommended to "make up" solutions with simple relations, either chemical or numerical, to the substances tested.

First.—A solution may be made up in such a way that its numerical relation to the substance which is to be determined shall be irregular. Such solutions are called "arbitrary." They are sometimes made so at first, and allowed to remain unadjusted. Often, however, a solution which was "made up" in some simple relation changes by standing. It is then "restandardized," that is, its present relation to a given quantity of the substance in question is ascertained.

Take the last equation given. Suppose that the solution is the salt (NaCl) and that having an "arbitrary" solution, *i.e.*, one made up by some rough guess, or quite at random, we find by experiment that 40 c.c. of it precipitates 0.096 gram silver. If we do not care to make the relation any simpler, we make a record usually placed on the bottle containing the solution, and reading something as follows:

"NaCl solution. 1 c.c. = 0.0024 gram metallic silver."

$$\left(\text{for } \frac{.096}{40} = 0.0024\right)$$

We shall give very few problems devoted to the relations and calculations resulting therefrom, of irregularly related solutions. They may be what is called "good practice," but they are on the whole poor laboratory practice, to be avoided when possible. If no other argument avails, the single one that the less calculation the less liability to error, seems to be final.

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Always try, then, to secure either "simple factor" solutions (see below), or "normal," the latter term including deci-, centi-, and any other submultiple of "normal." It is usually easy to secure a simple solution from a complex one (the terms being used of course in a purely arithmetical sense), and several problems are devoted to this point alone.

Second.—A solution may easily be so adjusted that a given volume of it bears a simple relation to a given weight of the substance "sought." Such solutions are called "simple factor" solutions.

Example.—A solution of potassium permanganate may be so made up that one c.c. equals exactly 0.01 gram of iron. Then, if we take for analysis one gram of the iron ore, each c.c. of the solution used indicates one per cent. of iron.

Suppose that in making up the solution it is made stronger than this. The procedure will now be to ascertain its exact strength in relation to a certain weight of iron, and then (usually by dilution) to reduce the solution to the required strength.

Let original strength be such that one gram of iron in solution requires only 70.5 c.c. of the permanganate for end reaction. Instead of keeping the solution as it is, and labelling it with the proper factor, as in the case of the silver solution above, we add to 70.5 c.c. of it 29.5 c.c. of water, thus making the 100 c.c. which will exactly correspond to 1 gram of iron.

To "make up" a liter of it we should take 705 c.c. and add 295 of water. Or, if we have a liter of the strong solution, and want to know how much water to add:

$$705 : 295 = 1000 : 418.4$$

that is, add to each liter of the solution, as it stands, 418.4 c.c. of water.

These "simple factor" solutions are very easy to calculate from, indeed in most cases there is no calculation required since the number of c.c. used gives the result in identical figures. They are most used in those cases, very numerous in technical work, in which a certain solution is employed for one determination, as, for example, a solution of sulphuric acid in gas testing, for determination of ammonia only.

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Third.—We may make a "normal" solution. This being an important convention, its theory will be set forth in considerable detail. We shall use the common abbreviation of "*N*" for normal, and in case of solutions which are submultiples of normal (tenths and hundredths), the fraction is prefixed. Thus *N* solution of HCl reads "normal solution of hydrochloric acid." Thirty c.c. of $\frac{1}{10}$ *N*. Na_2CO_3 reads "Thirty cubic centimeters of deci-normal solution of sodium carbonate."

"Cubic centimeter," however, is almost invariably "c.c.," even in speaking, in the laboratory.

A deci-normal solution is one-tenth the strength of a normal, a centi-normal is one-hundredth, and so forth.

There are three theories of "normal" solutions, but as one of them is now decidedly paramount, we shall use it alone, and to save the student we shall not even describe the "make-up" of the others.

The "normal" is based on the atomic weight of hydrogen. It might as well be based on the atomic weight of almost any other element, without making any difference in either theory or practice.

One liter of a normal solution contains or is equivalent to the atomic weight of hydrogen **taken in grams.**

Example.—One liter of "normal" KOH contains 1.008 gram hydrogen.

It also contains 16 grams of oxygen and 39.1 grams potassium.

Generally, the "normal" solution of any element will contain the "atomic gram weight" of that element, if the same be a monad, *i.e.*, "equivalent," atom for atom, to hydrogen. Certain special exceptions will be later noted.

Illustrations of the "normal" principle:

Take the acid HCl. Its molecular weight is 36.468, *i.e.*,

H.....	= 1.008
Cl.....	= 35.460
	36.468

Take the molecular weight in grams, then one liter of the *N* solution contains 36.458 grams of the compound HCl.

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Next take the alkali KOH:

K	= 39.10
O	= 16.00
H	= 1.008
	56.108

The molecular weight in grams will be 56.108 grams, contained in one liter.

These two compounds react as follows:

$$KOH + HCl = KCl + H_2O$$
$$56.108 + 36.468 = 74.56 + 18.016$$

Unless the student understands far less of the theory of chemical reactions than we have assumed at the outset, he will see at once that *one liter* of the one solution will exactly satisfy (in this case, "neutralize") *one liter* of the other. Necessarily, then, *any* volume of the one will exactly satisfy the same volume of the other.

Next take the acid H_2SO_4. Its molecular weight is 98.086. If we take 98.086 grams to a liter, however, we shall evidently have twice as much hydrogen (H_2) as in the last case. In order that the H here may be replaced by K as in that case, we should have to write the equation:

$$2KOH + H_2SO_4 = K_2SO_4 + 2H_2O$$

Evidently, in comparing the solutions, it is seen that it would take *two* volumes of the KOH solution to satisfy *one* of the H_2SO_4. So to get the "*N*" for the latter we must divide by two, thus:

$$\frac{98.086}{2} = 49.043^*$$

It is very important that the student should appreciate from the start the consequences of this conventional make-up of solutions. The "balance" is not only between certain solutions prepared with reference to one another, but subsists between *any* two which have been prepared on the normal basis.

* These first examples have been carried to third decimal place because at. wt. of H has a figure in that place. In all future cases, however, we shall carry expressions to second place only, carrying if necessary from third place. Thus for the three substances above we shall write, HCl = 36.47; KOH = 56.11 and H_2SO_4 = 98.09. Normal to liter for the latter would be H_2SO_4 = 49.04.

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Whether hydrogen or halogen, metal or radical, one liter, consequently one c.c., of any one ≡ one liter of any other. (The sign ≡ is used to signify "is equivalent to.") Also, any volume of an "*N*" sol. of a given element will carry the same weight of that element as the same volume of any other "*N*" solution which carries the same element, even though in a different combination.

This being both fundamental and important, an example follows.

Example. Normal solution of silver, one liter contains: silver 107.88 grams.

Normal solution of NaCl, one liter contains: Na, 23.0 grams; and Cl, 35.46 grams.

"*N*" solution of $BaCl_2$. According to system explained this must be $\frac{208.30}{2} = 104.15$, containing chlorine, 35.46 grams. Thus one c.c. of either the sodium or barium chlorides ("*N*") will exactly precipitate (satisfy equation) one c.c. of the ("*N*") silver solution.

By both principle and illustration, then:

1 c.c. of any "*N*" solution ≡ 0.001008 gram hydrogen.

1 c.c. of any halogen acid will contain 0.001008 hydrogen.

1 c.c. of any chloride will contain 0.03546 chlorine.

1 c.c. of any acid ("*N*") will exactly neutralize 1 c.c. of any *N* alkali.

1 c.c. of any element ("*N*") will contain $\frac{1}{1000}$ of the atomic gram weight of that element, if a monad; $\frac{1}{2000}$ if dyad, $\frac{1}{3000}$ if triad. (See below.)

The student who has grasped the principle of this method of adjusting solutions needs no further illustrations.

We here give a table of the more common normal solutions. Many substances are too strong as full normals, and in such cases it is usual to employ the deci-normal "$\frac{1}{10}N$" and often the centi-normal, "$\frac{1}{100}$ *N*."

The student should distinguish between normal solutions proper, and the so-called normal solutions which are often said to be "normal to each other." It is evident that two solutions may be arbitrarily made up in such a way that *any volume of the one shall be equivalent to an equal volume of the other.* This implies nothing as to any relation between volume and atomic weight.

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VOLUMETRIC NORMAL SOLUTIONS. WEIGHTS PER LITER.

Compound or element.	Atomic or molecular wt.	Grams per liter.
KOH	56.11	56.11
NaOH	40.01	40.01
NH_3	17.03	17.03
CaO	56.09 (÷ 2)	28.05
BaO	153.37 (÷ 2)	76.69
K_2CO_3	138.20 (÷ 2)	69.10
Na_2CO_3	106.00 (÷ 2)	53.00
HCl	36.47	36.47
HBr	80.93	80.93
HNO_3	63.02	63.02
H_2SO_4	98.09 (÷ 2)	49.04
$H_2C_2O_4$	90.02 (÷ 2)	45.01
H_3PO_4	98.06 (÷ 3)	32.69
Ag	107.88	107.88
I	126.92	126.92
$Ba^{''}$	137.37 (÷ 2)	68.69
$Al^{'''}$	27.10 (÷ 3)	9.03
NaCl	58.46	58.46
$BaCl_2$	208.29 (÷ 2)	104.15
$AlCl_3$	133.48 (÷ 3)	44.49

The second decimal places are hardly worth considering as a rule. If over five, carry 1 to first place, *e.g.*, $AlCl_3 = 44.49$. Call it 44.5.

Take any substance in the table, it is evident that to get the quantity in one c.c. we have only to divide by 1000.

Example:

Sodium carbonate, Na_2CO_3: One liter "*N*" contains 53.0 grams.
One liter $\frac{1}{10}$ *N* contains 5.30 grams.
One liter $\frac{1}{100}$ *N* contains .530 gram.
One c.c. *N* contains .0530 gram.
One c.c. $\frac{1}{10}$ *N* contains .00530 gram.
One c.c. $\frac{1}{1000}$ *N* contains .000530 gram.

Since then any volume of "*N*" solution satisfies the same volume of "*N*" solution of any other substance, the same must be good as between the $\frac{1}{10}$, $\frac{1}{100}$ or any other equalized relations to normal.

The student should now find it easy to "set up" for himself any number of illustrations, with these "type" cases before him. The practical use of normal solutions and their subdivisions belongs to laboratorial instruction.

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We have still to consider a class of solutions which cannot be brought strictly within the rules for normal cases. There are compounds whose "normal" for one reaction is not the same as for another, that is, it may be a "normal" in the one case and an "irregular" for another. The relation between the two cases may easily be calculated, but the irregularity remains. One of the most familiar of all volumetric reagents, potassium permanganate, comes under this class. It is also obvious that variant valence under different conditions destroys the strict rule for the "make-up" of normals.

In the case of "permanganate" as well as of several other common compounds, solution is rarely or never "made up" by weighing out a figured portion of the solid. Or rather, this is done as a mere approximation, and the solution is carefully tested ("standardized") afterward.

These special cases introduce no confusion in the subject. A few problems will show how to "convert" a solution for one element into a solution for another, simply by the calculation of a factor to be used in each analysis.

Even this might be dispensed with, if we chose to take the trouble to apply such a factor to the solution itself, instead of to the label.

See problem for deduction of magnanese factor, using "permanganate," from the already known factor for iron.

Although it somewhat invades the province of laboratory instruction, we may here slightly enlarge upon the remark made above as to method of obtaining an original "standard" solution whether normal or not. Certain solutions may be made with far greater accuracy by original "weighing out" of their required quantity, others may preferably be "standardized" after the make-up, and several can be obtained by the latter procedure only.

Examples.—(1) Silver. No comparison of a silver solution with another one can rival the accuracy of making an original silver solution by weighing out pure silver to the required amount and then dissolving it.

(2) Caustic potash (KOH). Any solution of KOH made by weighing out would be considered as a mere approximation, owing (*a*) to probable impurities,(*b*) to the great difficulty of weighing so hygroscopic a substance accurately.

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(3) Hydrochloric acid (HCl). Here we have the third case. We cannot weigh the gas, so we can get an accurate solution only by comparisons with others.

The following equations, nearly all of which are very familiar ones, will show how the calculation of the "normal" may have to vary from the set rule indicated above.

$$2KMnO_4 + 10FeSO_4 + 8H_2SO_4 = K_2SO_4 + 2MnSO_4 + 5Fe_2(SO_4)_3 + 8H_2O$$

Since we have here $2KMnO_4 = 10FeSO_4$ we see that the "normal" quantity for $KMnO_4$ must be $\frac{1}{5}$ of its molecular weight.

Practically, this solution is made by adjustment with metallic iron or an iron salt (ferrous-ammonium sulphate) and very commonly as a "simple factor solution" so that its normal value enters little into consideration.

$$K_2Cr_2O_7 + 6FeCl_2 + 14HCl = 2KCl + 2CrCl_3 + 6FeCl_3 + 7H_2O$$

Since one molecule of the chromate acts upon six molecules of the ferrous salt, take one-sixth of the formula weight of the former.

The reactions of oxalic acid show that both its hydrogen atoms are replaced in ordinary interchange, hence we take one-half its "weight" as the normal. Similarly for all ordinary di-basic acids.

Sulphurous acid may be estimated from its reaction with chlorine.

$$H_2SO_3 + Cl_2 + H_2O = H_2SO_4 + 2HCl$$

Hence normal quantity is:

$$\frac{H_2SO_3}{2} \text{ or } \frac{SO_2}{2}$$

Iron in changing from ferrous to ferric uses (theoretically or actually) only "one-half" of an oxygen atom. The expression is of course absurd in a theoretical sense, but useful in illustration. Thus:

$$2FeO + O = Fe_2O_3 \qquad (FeO + \tfrac{1}{2}O = FeO_{1\frac{1}{2}})$$

The "O" being regarded as derived from an oxidizing agent (say $KMnO_4$), we see *that in this relation* we must take the atomic weight of iron as "normal."

Using 56 as atomic weight of iron, let us ask as a problem:

"Permanganate" solution, standard for iron per c.c. being 0.0056,

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Required, "available" oxygen per c.c., according to following equations:

$$2KMnO_4 + 6HCl = 2KCl + 2MnCl_2 + 3H_2O + O_5 \quad (1)$$
$$2KMnO_4 + 10FeCl_2 + 16HCl = 10FeCl_3 + 2KCl + 2MnCl_2 + 8H_2O \quad (2)$$

Solution:

$$560 : 80 = 0.0056 : x \qquad x = 0.0008 = \text{available "O" per c.c.}$$

What is standard of the above solution for CaO?

$$Ans. \quad \frac{.0056}{2} = 0.0028$$

Let the student study the following equations carefully. The first one, showing oxidation of ferrous chloride by permanganate, will assist him in understanding why ferrous salts, *considered as reducing agents*, have their molecular weights (gram) as "normals" instead of half that weight.

3. Oxidation of ferrous chloride:

$$30FeCl_2 + 6KMnO_4 + 24H_2SO_4 = 20FeCl_3 + 5Fe_2(SO_4)_3 + 3K_2SO_4 + 6MnSO_4 + 24H_2O$$

4. Oxidation of ammonium oxalate $(NH_4)_2C_2O_4$:

$$5(NH_4)_2C_2O_4 + 2KMnO_4 + 8H_2SO_4 = 5(NH_4)_2SO_4 + K_2SO_4 + 2MnSO_4 + 10CO_2 + 8H_2O$$

5. Oxidation of ethyl alcohol, C_2H_5OH:

$$5C_2H_5OH + 12KMnO_4 + 18H_2SO_4 = 6K_2SO_4 + 12MnSO_4 + 10CO_2 + 33H_2O$$

6. Crystallized oxalic acid, $H_2C_2O_4 + 2H_2O$:

$$5H_2C_2O_4, 2H_2O + 2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 10CO_2 + 18H_2O$$

With these as types any case of permanganate oxidation may be solved.

We have finally to mention volumetric analysis by means of *two* solutions. For convenience these should be "normal to each other," if not made up to strict at. wt. normal. Obviously, any two strict *N* solutions are also "normal to each other."

In almost every case in practice the operation of a two-solution method consists in taking a fixed amount of one of them, subjecting it to whatever chemical reaction the particular

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analysis calls for, and then, with the other solution, determining the amount of the chemical change which has taken place. Technically, we are said to "titrate back" in using the second solution.

Examples. (1) In the analysis of illuminating gas, ammonia is determined by a process outlined as follows: A measured amount of the gas is made to pass through a solution of sulphuric acid, whose standard and volume are accurately known. Care is taken that the amount of acid shall be *more* than equivalent to any probable ammonia present in the volume of gas used. Now the acid is "titrated back" with an alkaline solution (it may be an ammonia solution as well as any other), which titration evidently determines how much of the acid was left *over and above the amount neutralized by the ammonia* in the gas. Subtracting this amount from the original quantity taken, we have the data for figuring the amount of ammonia present in the gas.

The reaction might be written thus:

$$H_2SO_4 + 2NH_3 + xH_2SO_4 = (NH_4)_2SO_4 + xH_2SO_4$$

That is, if we had taken $x + 1$ molecules of H_2SO_4 and 2 molecules of ammonia, we would still have to determine the "x" unsaturated molecules of the acid. The convenience of having the two solutions related by some very simple factor, or better, having them normal "*inter se*," needs no demonstration.

(2) In the "iodide" method for copper, the following equations define the reaction:

$$2CuSO_4 + 4KI = Cu_2I_2 + 2K_2SO_4 + I_2$$

Then,

$$I_2 + 2Na_2S_2O_3 = Na_2S_4O_6 + 2NaI$$

This is a case in which one solution (KI) need not be known. It is added in excess, but only so much of its iodine as corresponds to Cu_2 is liberated. The "hypo" solution which determines the iodine (2nd equation) is of course known in its relation to iodine, consequently to copper according to first equation.

"To avoid mistakes in calculating absolute strength of one solution from another, observe which is the stronger, and be sure that the calculated strength corresponds with this observation: the *stronger* solution is used in *smaller* volume than the

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weaker, when the two solutions are compared." (Prof. Horace L. Wells, "Chemical Arithmetic," p. 117.)

The error indicated is of precisely the same nature as may be made in determining volumes of gases according to changes in temperature or pressure. Inversion of fractions or logic is a common error. I have seen a student, after a careful but "inverted" calculation, deliberately dilute a solution already too weak.

When many determinations of the same kind are to be made and only regular "normals" are at hand, it lessens the computations to take, instead of ordinary fractions of a gram, or whole grams of the substance for analysis, *weights which have such a relation to the N solution that the reading in c.c. shall give the required percentage directly.* The "relation" is absolutely simple, however, and our problems open with illustrations of the principle, which is often used in gravimetric analysis also.

Miscellaneous Problems in Volumetric Analysis.

1. Having $\frac{1}{10}N$ acid solution, prepared for alkaline determinations, it is required to find the weights of various substances to be taken for determinations in order that *each c.c.* of the acid used shall indicate *one per cent.* of the constituent "sought."

Constituent sought.	Weights of substance to be taken.
Nitrogen (N)	0.1401 gram
Ammonia (NH_3)	0.1703 gram
Sodium carbonate (Na_2CO_3)	0.530 gram
Potassium carbonate (K_2CO_3)	0.691 gram
Sodium oxide (Na_2O)	0.310 gram
Potassium oxide (K_2O)	0.471 gram
Sodium hydroxide (NaOH)	0.4001 gram
Potassium hydroxide (KOH)	0.5611 gram
Calcium carbonate ($CaCO_3$)	0.5005 gram
Calcium oxide (CaO)	0.2805 gram
Barium carbonate ($BaCO_3$)	0.9870 gram
Barium hydroxide ($Ba(OH)_2$)	0.8571 gram

If the solution is full normal, take ten times these weights.
If the solution is $\frac{1}{100}N$ take one-tenth of these weights.
The student may now easily solve any parallel case.

2. $2KMnO_4 + 8H_2SO_4 + 10FeSO_4 = K_2SO_4 + 2MnSO_4 + 8H_2O + 5Fe_2(SO_4)_3$

This is the ordinary reaction of "permanganate" on ferrous salts.

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Required; Weight of permanganate per liter, if each c.c. of the solution equals 0.01 gram of iron, or, taking 1 gram for analysis, each c.c. = 1 per cent.

Solution.—The relation is 10Fe to $2KMnO_4$, numerically, 559 : 316.3. *Ans.* 5.658 grams per liter.

3. $3MnSO_4 + 2KMnO_4 + 2H_2O = 5MnO_2 + K_2SO_4 + 2H_2SO_4$

This is the equation for determination of manganese by the "permanganate" method. Having a solution of $KMnO_4$ standardized for iron, what factor is required for application when the same solution is to be used for manganese?

Solution.—Compare the equation with that in example 2 above. We see that in the first case $2KMnO_4 = 10FeSO_4$; and in the second, $2KMnO_4 = 3MnSO_4$. Take the exact figures for atomic weights (Fe = 55.84, Mn = 54.93), we have:

$$55.84 \times 10 = 558.4 \text{ and } 54.93 \times 3 = 164.79$$

If our iron "standard" is represented by unity (for example, 1 c.c. = 1 per cent.), then we may write:

$$558.4 : 164.79 = 1 : 0.295$$

Then 1 c.c. of the solution would indicate 0.00295 manganese, if the adjustment for iron had been 1 c.c. = 0.01 gram.

Ans. Factor = 0.295.

4. $5CaC_2O_4 + 2KMnO_4 + 8H_2SO_4 = 5CaSO_4 + K_2SO_4 + 2MnSO_4 + 10CO_2 + 8H_2O$

Equation of determination of lime (CaO) by "permanganate."

As in (2) above, having iron solution, determine "factor" to be used when same is to be used for CaO. We have 10Fe = 5CaO. Hence we need take only one-half of the iron indication, as the approximation of atomic weight of iron is so close to molecular weight of lime. (Fe = 56, CaO = 56 approx.) Thus, if 1 c.c. = 0.01 iron, then 1 c.c. = 0.005 lime.

5. Nineteen c.c. of $KMnO_4$ are required to oxidize 0.225 gram of ammonium oxalate, $(NH_4)_2C_2O_4 + 2H_2O$. Required the "standard," *i.e.*, weight per c.c., for iron. Use Fe = 56, etc.

$$5(NH_4)_2C_2O_4(H_2O)_2 + 2KMnO_4 + 8H_2SO_4 = K_2SO_4 + 5(NH_4)_2SO_4 + 2MnSO_4 + 18H_2O + 10CO_2$$

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Compare again with the equation for iron. That is, compare reaction of $2KMnO_4$ with oxalate and with iron, and deduce the relation of the two latter, on the principle that things equal to the same thing are equal (here equivalent) to each other. We have the old relation of $10Fe = 2KMnO_4$, also 5 of the "oxalates" equal to the same.

$$5\ \text{"}ox.\text{"} : 10Fe = 1 : x;\ i.e.,\ 800 : 560 = 1 : 0.7$$

Ratio therefore is 0.7. Now by terms of the problem $\frac{2.2.5}{1.9} = 0.0118$, that is, 1 c.c. of $KMnO_4 = 0.0118$ oxalate, multiply this by the ratio just found: $0.0118 \times 0.7 = 0.00826$.

Ans. 1 c.c. = 0.00826 metallic iron.

6. Taking a liter of the permanganate solution of example 5, how much water must we add to make 1 c.c. equivalent to 0.005 iron? *Ans.* 652 c.c.

7. See equation of reaction between crystallized oxalic acid and permanganate, under oxidation equations above. Fix standard for iron titration by oxalic acid. (Iron at 56 at. wt.)

$$H_2C_2O_4, 2H_2O = 126 \qquad Fe_2 = 112$$

$$\frac{112}{126} = \frac{8}{9}$$

Hence if we wish to "standardize" a solution for iron by means of the acid,

$$\frac{8 \times \text{oxalic indication}}{9} = \text{indication for iron}$$

8. $$H_2SO_4 + Na_2O = Na_2SO_4 + H_2O$$

If ten c.c. of H_2SO_4 precipitate five grams $BaSO_4$, how much water must be added to one liter, so that 1 c.c. equals 0.1 gram Na_2O? *Ans.* 329 c.c.

9. 5.3 grams sodium carbonate require 176 c.c. of a $\frac{1}{2}N$ solution of acid to neutralize. What is percentage of impurities in the sample? *Ans.* 12 per cent.

(The 5.3 is one-tenth of the 53 grams, or weight for 1 liter normal. If pure it would have neutralized 100 c.c. of normal acid, or 200 c.c. of $\frac{1}{2}$ normal. As it lacks 24 c.c., per cent. of impurities is evidently $\frac{1}{2}$ of 24 = 12.)

10. 1 gram of nitrogenous organic matter is treated with "soda-lime," which brings the nitrogen into form of ammonia,

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and the NH_3 is received into normal H_2SO_4 (100 c.c.). The latter is now "titrated back" with *N* alkali, of which 87 c.c. are required. What per cent. of nitrogen in the substance?

Solution.—The amount of nitrogen in 1 c.c. normal NH_3 is 0.014, which would of course neutralize 1 c.c. *N* acid. But it equals 13 c.c. normal acid, hence the amount of NH_3 is $0.014 \times 13 = 0.182$. $(100 - 87 = 13.)$

Ans. 18.2 per cent. nitrogen.

11. Using same solutions as in the last example, if we desire that each c.c. of the acid consumed by NH_3 shall equal 1 per cent. of nitrogen in the substance, what weight of the organic matter should we take to start with? See example 1.

Ans. 1.4 grams.

12. We "make up" haphazard a solution of permanganate, and standardize with 0.5 gram of iron wire, which contains 99.7 per cent. iron.

It takes 42.6 c.c. of this solution to react. We want a solution of which 1 c.c. = 0.005 Fe. How much water do we add to one liter of this solution? (Total volume 2.34 liters, subtract original liter.) *Ans.* 1.34 liters.

13. Solutions of Na_2CO_3 and HCl are equivalent ("normal to each other"). 100 c.c. of the acid acting on zinc evolve 100 c.c. of hydrogen. How many c.c. of the Na_2CO_3 will evolve 100 c.c of CO_2 gas when acted on by excess of any acid?

The equations are:

$$Zn + 2HCl = ZnCl_2 + H_2$$
$$Na_2CO_3 + 2HCl = 2NaCl + H_2O + CO_2$$

Ans. 100 c.c.

(For the relative amounts of the reagents in equal volumes, since they are mutually equivalent, is Na_2CO_3 and 2HCl.)

14. Wishing to get a silver solution with 0.01 gram of the metal in each c.c., and having only silver nitrate at hand, how much of this salt must be weighed out to make one liter of the desired solution? *Ans.* 15.7454 grams.

15. $$H_2S + I_2 = 2HI + S$$

Use nearest whole numbers for at. wts. In testing a spring water we make a solution of iodine, 25.4 grams to liter. Of this we place 100 c.c. in vessel and add the spring water under test. Of the latter 625 c.c. are required for the end reaction

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(disappearance of the starch-iodine blue). What *volume* of H_2S gas in one liter of this water? Use the "22.4" rule after getting weight of the gas. *Ans.* 358 c.c.

16. Two acid solutions intended to be each normal to a certain alkaline solution are respectively too strong and too weak. Of the strong, 70 c.c. neutralize 100 c.c. of the alkaline solution, while it requires 115 c.c. of the weak for the same volume (100 c.c.) of alkali.

We are now to mix the two acid solutions, mixture to be one liter in volume, so as to get a solution exactly "normal" to the alkaline solution.

Here is a good chance for "rational" arithmetic.

(1) As to the strong, it is obvious that if we add 30 c.c. of water to 70 c.c. of it, we get 100 c.c. of correct strength.

(2) As to the weak, it may be regarded in the light of 100 c.c. of correct strength, *plus* 15 c.c. of water.

$\frac{30}{15} = 2$. That is, $115 \times 2 = 230$ *c.c.* of the weak, added to 70 *c.c.* of the strong, will make correct mixture, 23 to 7. Divide the liter into 30 parts, taking twenty-three of the weak and seven of the strong.

Ans. Strong, $233\frac{1}{3}$ c.c. Weak, $766\frac{2}{3}$ c.c.

17. Same problem. The "weak" acid, however, is weaker, as it takes 117 c.c. instead of 115.

Ans. Strong, 253.19 c.c. Weak, 746.80 c.c.

18. Wanted iodine solution, of which 1 c.c. shall equal 1 c.c. of H_2S gas.

$$H_2S + I_2 = 2HI + S \qquad (H_2S = 34. \quad I_2 = 254)$$

We have weighed out 0.576 gram of iodine, what volume of solvent must be used? One liter of H_2S gas weighs 1.518 grams.

Ans. 50.8 c.c. = vol.

For 1 liter of it would contain 11.34 of iodine.

19. Wanted solution of "permanganate" of which 1 c.c. shall equal 0.01 gram of iron. We have a solution of which 20 c.c. = 0.24 iron. How much water to be added to a liter of this for the required strength? *Ans.* 200 c.c.

20. One gram of silver is dissolved and made up to 1 liter. We want a solution of NaCl which shall be "normal" to it. Trial solution of the salt precipitates 0.0015 AgCl for each c.c. How much water must be added to one liter of the salt solution?

Ans. 129 c.c.

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21. Chlorine is determined in water by solution of silver nitrate, using Ag_2CrO_3 as indicator. (That is, the highly colored silver chromate does not appear until all the AgCl is precipitated.)

For the silver solution 0.1 gram of metallic silver is dissolved in 1 liter. 6 c.c. of this solution bring end reaction with 100 c.c. of the water. How many parts chlorine in a million parts of water?

Solution.—Weight of silver used in the reaction = 0.0006.

$$107.88 : 35.46 = 0.0006 : 0.000197 \text{ (in 100 c.c.)}$$

Ans. Chlorine, 1.97 parts to million.

22. Taking above problem, and still using 100 c.c. of the water for analysis, we want a solution of silver such that *each c.c.* shall indicate 1 part in 1 million of chlorine. What weight of silver must we take for one liter of solution?

Solution.—In 100 c.c. (also grams) of the water, 1 part in million equals .0001.

$$35.46 : 107.88 = .0001 : .000304$$

Ans. For 1 liter take 0.304 gram Ag.

23. Solutions of NH_3 and H_2SO_4 are normal "to each other." 50 c.c. of the H_2SO_4 precipitate 1 gram of $BaSO_4$. How much NH_3 is there in 1 c.c. of its solution? (Approximate at. wts.)

Ans. 0.00292 gram in one c.c.

24. Wanted, solution of H_2SO_4 of which 1 c.c. $\equiv$ 0.001 of NH_3. 100 c.c. of a trial solution precipitate 0.711 $BaSO_4$. How much water must be added to 1 liter of the H_2SO_4 solution. (Approx. at. wts.) *Ans.* 36 c.c. water to one liter.

25. 1 c.c. of HCl solution $\equiv$ 0.010796 gram silver. 40 c.c. of same solution $\equiv$ 24 c.c. of an alkalin esolution. (Exact at. wts.)

Taking 0.5305 of impure Na_2CO_3 for analysis, we acidulate it with 100 c.c. of the HCl, boil off CO_2 gas remaining, and then "titrate back" excess of acid with the NH_3 solution, of which 9 c.c. are required.

What is per cent. of sodium carbonate in the sample?

Ans. 85 per cent.

Let the student, in verifying this, pay attention to the relation to "normal" as shown by figures of the first data.

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26. Wanted, 1 liter of solution of $K_2Cr_2O_7$, 1 c.c. to $\equiv$ 0.01 iron.

$$K_2Cr_2O_7 + 6FeCl_2 + 14HCl = 2KCl + 2CrCl_3 + 6FeCl_3 + 7H_2O$$

What weight of $K_2Cr_2O_7$ must be taken? (Exact at. wts.)

The 1 liter must be $\equiv$ 10 grams iron ($0.01 \times 1000 = 10$).

Ans. 8.7805 grams.

27. 1 c.c. of a $\frac{1}{10}$ *N* solution of HCl $\equiv$ 1.582 c.c. of NH_3. To what weight of Na_2CO_3 is 1 c.c. of this NH_3 equivalent? Note that we do not have to recur to the HCl in getting answer.

Ans. 0.003353 gram.

28. 1 gram of organic substance is taken for determination of nitrogen. NH_3 from the nitrogen is received in 50 c.c. *N* solution of HCl, which is now "titrated back" with *N* sol. of NH_3, using 41 c.c of same. What is percentage of nitrogen?

$$NH_3 + HCl = NH_4Cl \qquad (50 - 41 = 9)$$

Ans. 12.6 per cent.

29. If 10 c.c. H_2SO_4 precipitate 0.1631 $BaSO_4$, what weight of $NH_3 \equiv$ 1 c.c. of the acid? (Approx. wts.)

Ans. 0.00238 gram.

30. Same as above, but 50 c.c. H_2SO_4 precipitate 1.1 $BaSO_4$.

Ans. 1 c.c. $\equiv$ 0.00321 NH_3.

31. $MnO_2 + 2FeCl_2 + 4HCl = MnCl_2 + 2FeCl_3 + 2H_2O$.

Half a gram of iron dissolved in excess of hydrochloric acid, with one gram of manganese ore. Upon titration we find 0.285 iron. Using approx. wts., what per cent. of MnO_2 in the ore?

Solution.—Since 0.285 iron is unchanged, 0.215 entered the reaction, as per equation. We have $Fe_2 \equiv MnO_2$, hence:

$$112 : 87 = 0.215 : 0.167$$

Ans. 16.7 per cent. MnO_2.

32. Analysis of coal gas for ammonia. 1 c.c. $H_2SO_4 \equiv$ 0.56 NaOH (gram). Into 50 c.c. of the acid pass whatever quantity of gas is required by test, then titrate back with the NaOH soltion, *using* 14 *c.c.*

What volume of the acid was neutralized by the NH_3?

Ans. 25 c.c.

33. 11.9922 grams silver are made up to 1.1111 liters in solution. What is now the relation to "normal" of this solution?

Ans. $\frac{1}{10}$ normal.

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34. Two solutions are of equal volume. One contains 6.4935 grams of NaCl, the other 94.3167 of $AgNO_3$. What is their numerical relation in the "normal" adjustment?

Ans. The silver solution is five times the salt. That is, if the silver is N the salt is $\frac{1}{5}$ N.

35. We have $KMnO_4$ solution of which 1 c.c. $\equiv$ 0.02 Fe. Take 2.5 grams for analysis, and use 80.5 c.c. of this solution, what is the per cent. of iron in the ore?

Ans. 64.4 per cent.

36. We have a solution of iodine, made by weighing out the solid, and containing 4 grams to the liter. Taking 100 c.c. of this, we pour in the water which is under examination for its contents of H_2S gas, and get end reaction at 850 c.c. of the water.

$$H_2S + I_2 = 2HI + S$$

What *volume* of H_2S gas in 1 liter of the water?

Ans. 0.0414 liters.

37. Phosphorus can be precipitated as $(NH_4)_3PO_4 + 12MoO_3$. The relationship to be considered is $P \equiv 12MoO_3$; numerically 31 : 1728.

Solution of the "yellow precipitate" being reduced, the MoO_3 becomes Mo_2O_3 (*i.e.*, $2MoO_3$ becomes Mo_2O_3) and titration with permanganate gives following equation (use approx. wts. throughout. Fe = 56, etc.):

$$5Mo_2O_3 + 6KMnO_4 + 9H_2SO_4 = 10MoO_3 + 3K_2SO_4 + 6MnSO_4 + 9H_2O$$

Compare this with the equation:

$$2KMnO_4 + 10FeSO_4 + 8H_2SO_4 = K_2SO_4 + 5Fe_2(SO_4)_3 + 2MnSO_4$$

If we seek a relation from an already made solution of $KMnO_4$ adjusted for iron, to one for phosphorus, according to these ratios (or say we want a "factor" to pass from the iron to the phosphorus relation for the $KMnO_4$ solution) we calculate as follows: In the first equation $6KMnO_4 \equiv 10MoO_3$, while in the second equation (since $2KMnO_4 \equiv 10$ Fe), $6KMnO_4 \equiv 30$Fe. Putting equivalents to same, as equivalents to each other, we have $10MoO_3 \equiv 30$Fe. This reduced to its lowest terms becomes $MoO_3 \equiv 3$Fe, or, numerically, 144 molybdic anhydride $\equiv$ 168 iron.

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Returning now to the first comparison, *i.e.:*

$$P : 12MoO_3 = 31 : 1728$$

we see that 31 grams phosphorus corresponds to $\frac{168}{144} \times 1728$ grams metallic iron, easily reducible to the ratio:

$$Fe : P = 1 : 0.01538$$

That is, a $KMnO_4$ solution which for a given volume $\equiv$ 1 Fe, corresponds to only 0.01538 phosphorus in the titration for phosphorus as given in the first equation in this section.

The figures (ratio) may of course be made to apply to either weights or percentages, according to circumstances.

38. Permanganate is so adjusted that 1 c.c. = 0.01 iron. From one gram of ore the yellow precipitate is obtained, reduced and titrated with the permanganate solution. It takes 15 c.c. for the reaction, what is the percentage of phosphorus in the ore?

Solution: $1 : 0.01538 = 15 : 0.2307$

Ans. 0.2307 per cent.

39. Permanganate solution, 1 c.c. = 0.013 iron. Take 5 grams of iron ore for phosphorus, we find by titration with $KMnO_4$ of the yellow precipitate that it requires 45 c.c. for end reaction. What per cent. of phosphorus in the ore?

Ans. 0.1799 per cent.

40. $Mn_2P_2O_7$ contains 50 per cent. of phosphoric anhydride (P_2O_5). A certain weight of this substance being taken and dissolved, phosphorus is obtained as the molybdate precipitate ("yellow ppt.") the latter dissolved and titrated with $KMnO_4$ sol. of such strength that 1 liter = 40.31 grams iron.

It takes 1 liter of the $KMnO_4$ solution to react. What weight of the phosphate was taken? *Ans.* 2.84 grams.

41. 10 c.c. H_2SO_4 precipitate 0.124 $BaSO_4$. 10 c.c. $NH_3 \equiv$ 14 c.c. HCl. 100 c.c. of the HCl precipitate 2 grams of AgCl.

Which is the stronger, the H_2SO_4 or the NH_3 solution? How many c.c. of water must be added to 1 liter of the stronger to equalize the solutions?

Ans. The NH_3 is the stronger. Add 0.8383 liter to 1 liter.

NOTE.—Some of the problems above have been computed with "weights" of 1907. (Mn. = 55, Ag = 107.93, etc.) The differences in answers are trivial.

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MISCELLANEOUS PROBLEMS.

NOTE.—In analytical determinations exact atomic weights are used, in others nearest whole number except Cl = 35.5, unless otherwise indicated.

Table III may be taken as a collection of problems involving either deduction of formula from analysis or the reverse. It is computed from 1912 data.

1. Alloy of copper (8.9 sp. gr.) and silver (10.5 sp. gr.) weighs 100 grams, its sp. gr. is 9.7, what were weights of the two metals?

2. We want 100 liters of N_2O gas. What weight of ammonium nitrate must be taken? ($NH_4NO_3 = N_2O + 2H_2O$.)

3. A hydrocarbon burns producing 2 liters of CO_2 gas and 3.214 grams of water. What hydrocarbon is it, and what volume of it was burned?

4. 100 grams iron are dissolved in 200 grams sulphuric acid. What volume of ammonia solution neutralizes excess of acid, solution having sp. gr. 0.9 and containing 28 per cent. ammonia gas by weight?

$$Fe + H_2SO_4 = FeSO_4 + H_2 \qquad 2NH_3 + H_2SO_4 = (NH_4)_2\,SO_4$$

5. A liter of gas at temperature 35° Centigrade, is cooled without change of pressure to −35° C. What is now its volume?

6. Calling densities of H_2 and N_2 at 0°, respectively 2 and 28, at what temperature will density of nitrogen equal that of hydrogen at zero C.?

7. Ten grams of a liquid, sp. gr. = 3, just fill a spherical bulb. What is the internal radius of the bulb?

In this and all similar problems, the expression for the volume, geometrically speaking, must first be equated with the known volume.

We have here to start with:

$$\frac{4\pi R^3}{3} = 3.33\dot{}$$

8. Solution of stannous chloride derived from *one gram* of substance is oxidized by excess of ferric chloride:

$$SnCl_2 + 2FeCl_3 = SnCl_4 + 2FeCl_2$$

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The $FeCl_2$ is now "titrated" with solution of "permanganate" containing six grams of the pure salt to one liter of solution:

$$6KMnO_4 + 30FeCl_2 + 24H_2SO_4 = 20FeCl_3 + 5Fe_2(SO_4)_3 + 3K_2SO_4 + 6MnSO_4 + 24H_2O$$

It requires 16.45 c.c. of the $KMnO_4$ solution, what is percentage of tin in the substance?

(NOTE.—Use the last equation first, finding weight of iron. Apply the data obtained to the first equation.)

9. A lead-lined cylindrical tank, 5 meters deep and 5 meters in diameter, is full of water, which, being drawn off and evaporated with a little sulphuric acid, yields 1437.05 grams of lead sulphate ($PbSO_4$).

What was the percentage of *lead* in the water?

10. $$PbCl_2 + 2AgNO_3 = Pb(NO_3)_2 + 2AgCl$$

In this reaction, 2.5 grams of the lead chloride were taken, and 2.58 grams of the silver chloride obtained. Assume approx. at. wts. for silver and chlorine. Find atomic weight of lead.

11. $$4FeS_2 + 15O_2 + 8H_2O = 2Fe_2O_3 + 8H_2SO_4$$

This equation shows roughly the production of sulphuric acid from pyrite. Suppose the pyrite has 7½ per cent. impurities, and that five per cent. of the sulphur is lost in the operation. What weight of H_2SO_4 is produced from one ton of the pyrite?

12. The weight of one liter of air at 0° C. and normal pressure, is 1.293 gram. What will it weigh at normal pressure and 300° C.?

13. A liter of oxygen under normal p. and t. weighs 1.429 gram. At what temperature will a liter of it weigh one gram?

14. A mixture of carbon oxide (CO) and hydrogen (46.5 c.c.) is exploded with excess of oxygen. After the explosion there remain 35.35 c.c. of permanent gas, of which KOH solution absorbs 18.60 c.c., leaving for the residual or excess oxygen 16.75 c.c.

Required, original volumes of CO and hydrogen gases, also the volume of oxygen added.

$$2CO + O_2 = 2CO_2$$
$$2H_2 + O_2 = 2H_2O$$
$$2KOH + CO_2 = K_2CO_3 + H_2O$$

This may be most easily worked back from the absorption figure for CO_2 gas.

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15. What will one liter of chromium hexafluoride weigh (CrF_6)? (Use the "crith," at 0.0896.)

16. Ammonium.- Xorthophosphate (NH_4XPO_4) which weighs one gram, is heated, becoming X-pyrophosphate which weighs 0.84524 gram. What is the atomic weight of "X."

($2NH_4XPO_4 = 2NH_3 + H_2O + X_2P_2O_7$.)

17. 21 c.c. of $FeSO_4$ solution require 22.05 c.c. of a solution of potassium bichromate containing 5 grams of the salt to one liter. What weight of iron in one c.c. of the iron solution? ($6FeSO_4 + K_2Cr_2O_7$, etc.)

18. One gram of lead is dissolved and into the solution is passed sulphuretted hydrogen gas (H_2S) one liter. What is excess of the latter in weight and in volume? (Use approximate at. wts., and the "crith" method, crith = 0.0896.)

19. If the molecular weight of aluminum chloride is 267.2, what is its formula, and what would be the theoretical weight per liter of its vapor?

20. One hundred liters of ammonia gas are passed into 100 grams of sulphuric acid. What is the excess, in volume and in weight, of the ammonia?

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

21. A solution of silver nitrate is divided into two equal parts. One of these yields a precipitate of one gram of silver chloride. To the other, one gram of sodium chloride is added. Which is in excess, and by what weight?

22. A certain amount of CaO being converted into $CaSO_4$ gains 4 grams in weight. What was its weight as CaO?

23. $$FeS + H_2SO_4 = FeSO_4 + H_2S$$

What weight of the sulphide must be taken to obtain one liter of the gas? (Iron at 56, etc.)

24. Sulphuric acid of 1.8 specific gravity contains 96 per cent. of real acid. What weight of H_2SO_4 is there in 100 c.c. of the same?

25. The iodide of a monad metal, MI, weighs 46.9 grams. Converted into the fluoride, MF, it weighs 9.1 grams. If atomic weight of iodine is 127, what is atomic weight of "M?"

26. One kilogram of sea water, sp. gr. 1.026, has what volume?

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27. What length of copper wire (specific gravity = 8.9), one millimeter in diameter, will be dissolved by one kilogram of nitric acid containing 24 per cent. of HNO_3?

$$3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 4H_2O + 2NO$$

28. Ten grams of a salt soluble in water lose 3.5 grams when weighed in gasoline.

Eighty-seven grams of the gasoline fill a flask which holds 100 c.c. of water. What is specific gravity of the salt?

29. Air is heated from 0° to 819° C. Pressure remaining constant, how much of the original air remains in the flask?

30. $$AgBr + Cl = AgCl + Br$$

If we take atomic weight of chlorine as 35.45 and that of bromine as 79.96, if weight of the AgBr is 1.6916, what is weight of the AgCl?

31. The sulphide of a dyad metal "RS" contains 33 per cent. sulphur. What is the atomic weight of "R?"

32. $$NH_4X + KOH = KX + NH_4OH$$

Take ten grams of the NH_4X. The NH_3 evolved (NH_4OH) is absorbed in water, and neutralizes 675.7 c.c. of solution of sulphuric acid.

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

Ten c.c. of this acid precipitate 0.466 gram $BaSO_4$. Using approximate atomic weights, find atomic weight of "X."

33. One pound of sulphuric acid (H_2SO_4) acts on one pound of ferrous sulphide FeS. Find excess of the latter.

34. $$Zn + H_2SO_4 = ZnSO_4 + H_2 \qquad (Zn = 65)$$

Take two lbs. of zinc and three lbs. of sulphuric acid, which is in excess, and by how much?

35. A solution of HCl precipitates 1 gram of AgCl for each 50 c.c. of the solution used. 4 liters of ammonia gas are passed into 1 liter of the HCl solution; give both weights and volumes of excess and deficiency.

36. (Approx. wts.) Solution of H_2SO_4 is of such strength that 1 c.c. precipitates 0.0233 gram of $BaSO_4$. Into 100 c.c.

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are passed 100 c.c. of ammonia gas. Find weight excess and deficiency. ($2NH_3 + H_2SO_4 = (NH_4)_2 SO_4$.)

37. $$S_2 + 3O_2 + 2H_2O = 2H_2SO_4$$

We have pyrite containing 50 per cent. of sulphur. In the operation of making sulphuric acid, 96 per cent. of the sulphur goes into the acid and 4 per cent. is lost. What weight of pyrite will produce 100 tons of the acid?

38. $$Sb_2S_3 + 6HCl = 2SbCl_3 + 3H_2S$$

What volume of the gas is obtained from 1 kilo of the antimony sulphide?

39. We have 100 grams of lead in solution. If we have sulphuric acid of 91 per cent. H_2SO_4, and 1.75 sp. gr., what volume of same will precipitate the lead?

$$Pb(NO_3)_2 + H_2SO_4 = PbSO_4 + 2HNO_3$$

40. A mixture of carbonic acid gas (CO_2) and air is at 20° C. CO_2 being absorbed out, heat must be raised to 215.3° to restore residual air to the original volume of the mixture. What were the relative volumes of the two originally? (Call original volume unity.)

41. In the analysis of a sample of hematite, each portion taken for partial analysis being 1 *gram*, we have the following precipitates and titration.

For silica	0.0731 gram	SiO_2
For magnesia (MgO)	0.0441 gram	$Mg_2P_2O_7$
For manganese	0.0512 gram	$Mn_2P_2O_7$
For aluminum	0.0246 gram	Al_2O_3
By ignition	0.0103 gram	loss

Titration for iron, 54.05 c.c. used of a solution of $KMnO_4$ of which 1 c.c. = 0.011 iron.

Write out the complete analysis, giving manganese as MnO and assuming the "loss" as water. Give both metallic iron and percentage as Fe_2O_3.

42. A dyad metal has RO for formula of its oxide and RCl_2 for chloride. A portion of the oxide weighs 1.1 and when converted into chloride weighs 1.8442 grams. If at. wt. of chlorine is 35.4 what is at. wt. of this metal?

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43. "Pulp and scales." Wt. of pulp 58 grams, scales wt. 0.016 gram. Assay of pulp 0.34 oz. to ton. Wt. of metal in scales 0.014 gram. What is assay per ton?

44. One-third of an assay ton yields 0.008 gram gold. One-fifth of an assay ton yields button of gold and silver weighing 0.1348 gram (same ore). What is the assay, in gold and silver?

45. $$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$$

We want 200 kilos of 20 per cent. HCl acid. What weight of sodium chloride must be taken?

46. $$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2$$

Pyrolusite containing 80 per cent. of MnO_2 is treated with HCl acid containing 30 per cent. of HCl. We have 10,875 lbs. of the mineral, how many lbs. of the acid must be taken?

47. A substance appears to weigh 10.7 grams when placed on one side of an untrue balance and 10.6 grams when placed on the other. What is the true weight?

48. Same as 47, but the two weights are 2 and 2.5.

49. $$2C_6H_6 + 15\,O_2 = 12CO_2 + 6H_2O$$

In this reaction 31.8384 grams of water were produced. Find all the other terms in liters.

50. Sp. gr. of water = 1. Mercury 13.596. Alcohol 0.81. Sulphuric acid 1.85.

When the mercury barometer stands at 76 centimeters, at what height will barometers filled with the other liquids stand?

51. What is the weight of a liter of air at 30° C. and 750 mm.? (Normal, 1.293.)

52. "Pulp and scales." Wt. of "pulp" 87.478 grams. Assays zero. Scales weigh 0.020 and metal from same 0.018 gram. Find assay in oz. to ton.

53. 1722 grams of ore yield 0.02792 gram gold. Find assay in ounces to ton.

54. An ore contains 13 per cent. water. When dried it assays 58.62 per cent. metal. What would it assay before drying?

55. An ore contains 50 per cent. of metal. As charged into the furnace it has ten per cent. of its weight of barren flux added to it. What is assay of the "charge."

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56. A hydrocarbon burns, producing 24 liters CO_2 gas, and 9.648 grams water. Volume of the original gas, 4 liters (that is, its theoretical volume, when reduced to 0° and 760 mm.) What was its formula?

57. Ferric-ammonium and ferrous-ammonium sulphates have the respective ratios as to acid and basic radicals indicated by their names, but they crystallize with different numbers of molecules of water. Each of these salts, as crystallized, contains exactly one-seventh of its weight of iron. Find the formulæ of the crystallized salts.

58. We have a mixture of 4 tons of ore assaying 103 ounces to ton; 11 tons of ore assaying 57 ounces to ton; 2 tons of ore assaying 203 ounces to ton. What is assay of the mixture?

59. One liter of CO_2 gas at 10° C. is passed through solution of $Ba(OH)_2$. What weight of $BaCO_3$ is precipitated? (Approx. wts.)

$$Ba(OH)_2 + CO_2 = BaCO_3 + H_2O$$

60. Two liters of HCl gas are passed into a solution of 10 grams of silver.

$$AgNO_3 + HCl = AgCl + HNO_3$$

Which is in excess, and how much?

61. What is the weight of 1 liter of oxygen 16° C. and 745 mm.?

62. $H_2O = H_2 + O$. 10 grams water. What volumes of the gases?

63. What weight of zinc will yield 10 cubic meters of hydrogen at 15° C. and 740 mm.?

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

Zn at 65 at. wt. "22.4" method.

64. Ten grams of H_2O_2 (hydrogen peroxide) yield how many times their volume of oxygen, on heating?

$$H_2O_2 = H_2O + O \qquad \text{Sp. gr. of } H_2O_2 = 1.455$$

65. An ore which contains 4 per cent. of water assays 53.76 ounces. What will it assay after drying?

66. An unweighed lot of ore is sampled and found to contain 7 per cent. water. It is rained on, and being now weighed gives 21,000 lbs. and 10 per cent. water. What was weight as received?

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67. An ore containing "*a*" per cent. of water assays when dry "*b*" per cent. What would it assay "wet?"

68. Two ores have: (1) Silica, 40 per cent. FeO, 20 per cent.
(2) Silica, 10 per cent. FeO, 81 per cent.
Taking 1000 lbs. of No. 1, how many lbs. of No. 2 must be added in order that the silica and iron oxide in the mixture shall be equal in weight?

69. We have pyrite containing 42 per cent. sulphur. Product contains 75 per cent. H_2SO_4. ($S_2 + 3\ O_2 + 2H_2O = 2H_2SO_4$.) What weight of FeS_2 for 100 tons of this product?

70. In the analysis of a spring water, one-liter portions are taken for the various determinations. It contains sulphates, chlorides, carbonates.

Analytical products weigh as below. Calculate the analysis in parts per 100,000. Residue weighs 0.9324 gram. Use exact atomic weights, Table I.

For total chlorine; AgCl	1.3225
For total lime, CaO; $CaSO_4$	0.4180
For total KCl + NaCl; KCl + NaCl	0.3460
For total SO_3; $BaSO_4$	0.6417
For total Mg; $Mg_2P_2O_7$	0.2104
For total K; K_2PtCl_6	0.4164

Method of "adjudication." All SO_3 to CaO. Excess of CaO as carbonate. All others distributed as chlorides. Show two summations, one of elements and radicals, the other of proximate constituents. (Compounds.)

71. A closed vessel is filled with air at 0° C., and 760 mm. Heated to 546° C. What is now the pressure in atmospheres? (760 mm. = one atmosphere.)

72. Having taken 2.7273 grams of pig iron for determination of carbon, that element is burned by suitable means, resulting CO_2 gas being absorbed in a KOH bulb. ($2KOH + CO_2 = K_2CO_3 + H_2O$.) Weight of the bulb increases 0.125 gram. What is the percentage of carbon?

73. Phosphorus is often determined as $Mg_2P_2O_7$. If we wish the weight of this product to express directly the weight of the phosphorus in ten grams of the material under analysis, what weight of the latter should be taken?

74. "Pulp and scales." Weight of ore taken, 110.5 grams; assay to ton, 50 oz.; weight of "scales," 0.220 gram; weight

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of metal in same, 0.209 gram. Find correct assay per ton of sample.

75. $2KOH + CO_2 = K_2CO_3 + H_2O$

In this equation the caustic potash weighs 11.2 grams, what is volume of the CO_2 gas at 91° C.?

76. $FeS + H_2SO_4 = FeSO_4 + H_2S$

Volume of the gas being 2.232 liters, what is weight of the H_2SO_4?

77. The iodide of a monad metal "M" weighs 3.3000 (MI). Being converted into the chloride (MCl) the latter weighs 1.2870.

Find atomic weight of "M." (Take iodine at 127, chlorine at 35.5.)

78. Crystallized copper sulphate has the formula $CuSO_4 + 5H_2O$. Being dissolved in water and precipitated by H_2S gas we have the equation:

$$CuSO_4 + H_2S = CuS + H_2SO_4$$

If we wish to prepare 1 liter of normal sulphuric acid according to this reaction, what weight of the crystallized sulphate must we take?

79. Pulp and scales—two metals. Ore weighs 102 grams; silver, 106 oz. to ton; gold, 2 oz. to ton. Scales weigh 0.5 gram; silver, wt. = 0.4 gram; gold, wt. = 0.08 gram. Find assay to ton for silver and gold of the sample.

80. A lot of iron ore loses 962 lbs. by drying, and assays (dry) 54 per cent. iron. Its weight as received was 26,000 lbs. What would it have assayed "wet."

81. A closed vessel contains air at 1 atmosphere and 20° C. To what temperature must it be heated in order that the tension be raised to four atmospheres?

82. $PbCl_2 + CO = Pb + COCl_2$

Using exact atomic weights, if we take 31 grams of the lead chloride, what volume of carbonyl chloride shall we obtain?

83. Explain why the "dissociation" of H_2SO_4, NH_4Cl and PCl_5 under heat, produces twice the volume (hence $\frac{1}{2}$ the density) of the theoretical gas volumes and densities of these substances.

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Assume such quantities as would yield 2 liters each of the vapors, if dissociation did not take place. The gases into which these substances dissociate are probably as below:

$H_2SO_4 = SO_3 + H_2O$. $NH_4Cl = NH_3 + HCl$. $PCl_5 = PCl_3 + Cl_2$

84. $NaCl + AgNO_3 = AgCl + NaNO_3$

How much sodium chloride must be dissolved in 1 liter of water in order that 1 c.c. of the solution shall precipitate 0.01 gram of silver?

85. The oxide of a dyad metal "R" is reduced by hydrogen. $RO + H_2 = R + H_2O$. If RO weighs 1 gram, and H_2O weighs 0.2274 gram, what is the atomic weight of "R?"

86. $2COS + 2PH_3 + 7\ O_2 = 2CO_2 + 2SO_2 + P_2O_5 + 3H_2O$

(*a*) What is the density of the entire first member considered as a mixture, *i.e.*, before the explosion with oxygen?

(*b*) If volume of the first member were 8.14 liters, what is volume of "permanent gases" in the second member?

87. At what pressure will 1 liter of air weigh two grams, $t = 0°$ C.? (Normal weight, 1.293.)

88. 85 c.c. gas at 20° C. and 580 mm. What volume at 0° C. and 760 mm.?

89. To what temperature must an open vessel be heated in order to drive out $\frac{1}{4}$ of the air contained at 0° C.? (Call $V = 1$.)

90. A sphere 2 cm. in diameter weighs 7.3304 grams. If it "just floats" in a liquid, what is the sp. gr. of that liquid? (Surface of liquid tangent to upper point of the sphere.)

91. Placing in a crucible some dried calcium oxalate, CaC_2O_4, the whole is weighed, giving 13.4270 grams. Crucible and contents are ignited, leaving CaO. Weight of crucible and contents is now 13.2038, what is weight of crucible, and of the CaO?

92. Specific gravity flask filled with water weighs 30 grams. 4 grams of a mineral is placed in it, flask filled with water to same mark, and now weighs 33.2 grams. Find sp. gr. of the mineral.

93. Two lots of ore are weighed, assaying respectively 88 and 106 oz. to ton. Mix assays 100 oz. It is dried, loses 400 lbs. water, and now assays 102 oz. What were original weights in tons?

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94. In a mixture or alloy of two substances (no allowance being made for change of volume in mixing) what proportion must be observed if the sp. gr. of the mixture is to be the mean of the specific gravities of the two?

95. A closed vessel at 983° C. has internal gas pressure of one atmosphere. It is now cooled to 41° C. What is now the tension, in atmospheres?

96. Analysis of a spring water. One liter yields 1.9138 grams solid residue. Following are weights of analytical precipitates or products:

For SO_3; $BaSO_4$	0.8260
For lime, CaO	0.0873
For sodium, NaCl	1.3910
For chlorine, AgCl	3.6280
For magnesium, $Mg_2P_2O_7$	0.3050

It contains also H_2S gas in solution. This is determined by iodine.

$$I_2 + H_2S = 2HI + S$$

The iodine solution contains 1 gram iodine to the liter. It requires 881.4 c.c. of the spring water to bring the end reaction with 100 c.c. of solution.

All the gravimetric determinations are made on 1 liter portions. Write analysis in parts to 100,000, and volume per liter of the H_2S gas.

Make out also separate statements for the various elements, which must in their summation check with the total analytical results by compounds, and with the total solid residue.

Lime as usual, to SO_3 radical, excess of the latter to sodium, excess of sodium to chlorine, excess of chlorine to magnesium.

97. An open vessel at temperature 16° C. is heated to 305°, then sealed and cooled back to 16°. What is now the tension (atmospheres)?

98. We have a silicate $RSiO_3$. In this, R being a dyad metal, the percentage of "R" is 23.6. Find its atomic weight, Si = 28.4.

99. $$H_2 + O = H_2O$$

What is the density of the mixture of two volumes of hydrogen and one of oxygen (without combination), and what is the theoretical density of steam at 0° C.?

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100. A pyritous zinc ore is roasted until all the FeS_2 is judged to be oxidized to Fe_2O_3, the zinc being now distributed in the three forms of ZnS, ZnO and $ZnSO_4$.

One-gram portions are taken for analysis; following weights are obtained:

Silicious matter	0.0805
For total zinc, ZnO	0.5246
For total sulphur, $BaSO_4$	1.2127
For SO_3, $BaSO_4$	0.6710

Iron is estimated by titration, one gram portion used. Used 11.1 c.c. of a permanganate solution of which 1 c.c. = 0.008 iron.

Write out complete analysis, making summations both by compounds and by elements, *e.g.*, find percentages of ZnO, Fe_2O_3, etc., also percentages of all the separate parts, such as O in ZnO, S in ZnS, SO_3.

101. Using 137 as at. wt. of barium, find atomic weight of the metal "R" when 1 gram of RSO_4 yields 1.5432 grams $BaSO_4$.

102. A flask weighing when empty 35 grams, weighs 93 grams when full of water and 114.016 when filled with HCl solution. Find sp. gr. of the latter.

103. $$RS + H_2SO_4 = RSO_4 + H_2S$$

In this equation weight of RS = 1 gram. Volume of H_2S evolved is 256.5 c.c. Find atomic weight of "R."

104. $$2H_2S + 3O_2 = 2H_2O + 2SO_2$$

What volume of *air* for the combustion of one liter of H_2S gas, air containing 21 per cent. by volume of oxygen? State volume of both air and oxygen in the air.

105. One liter of water *at maximum density* forms what volume of steam at 300° Centigrade?

106. In a specific gravity bottle whose weight when filled with water alone is known, 19.25 grams of sand are placed and the bottle filled with water. Gain in weight over water alone is 11.55 grams. Find sp. gr. of the sand.

107. $$CO + Cl_2 = COCl_2$$

What is the density of the mixture in the first member of this equation. What is the density of the carbonyl chloride when

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formed? If the oxygen, separately considered, was $1\frac{1}{2}$ liters in volume, what were volumes of the CO, Cl_2 and of the $COCl_2$?

108. We have ten grams of H_2SO_4 in water and pass in one liter of ammonia gas (NH_3). What is deficit in weight of the latter?

$$H_2SO_4 + 2NH_3 = (NH_4)_2SO_4$$

109.
$$S + O_2 = SO_2 \quad (1)$$
$$SO_2 + 2H_2O + Cl_2 = 2HCl + H_2SO_4 \quad (2)$$
$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2 \quad (3)$$

8.22 grams of sulphur are burned, the product (SO_2) caught in water, oxidized as shown in equation (2), the chlorine in this equation being produced as in equation (3).

What weight of manganese di-oxide is required to yield the necessary quantity of chlorine? What weight of air (23 per cent. oxygen) burns the sulphur? Solve without any calculation of the weight or volume of chlorine used.

110. Find a factor to pass from $Na_2CO_3 + 10H_2O$ to Na_2CO_3. Also factor to pass from Na_2CO_3 to $Na_2CO_3 + 10H_2O$.

111. What volumes of oxygen burn, respectively, one liter each of the following gases (PH_3 supposed to burn H_3PO_4):

$$CO\ ;\ CH_4\ ;\ C_2H_4\ ;\ C_2H_2\ ;\ H_2S\ ;\ PH_3$$

112. What weight of caustic potash (KOH) is neutralized by 50 c.c. of $\frac{1}{10}$ *N.* acid?

113. 10 grams of oxygen and 10 grams of carbonous oxide (CO) are mixed and exploded. ($CO + O = CO_2$.) The resulting CO_2 being absorbed out, what volume and weight of oxygen remain? What were volumes of the two original gases?

114. Analysis of ore. The arsenic in this analysis is precipitated as Ag_3AsO_4. This is dissolved in nitric acid, the silver precipitated as AgCl, which is weighed. Other constituents determined in usual methods. The chloride of silver, AgCl, weighs 0.2099. $BaSO_4$ (for sulphur), 1.378. Ferric oxide, Fe_2O_3, 0.2624. Cuprous sulphide, Cu_2S, 0.0533. SiO_2, 0.4627. Stannic oxide, SnO_2, 0.0824. Above weights are all in grams, *portions taken for analysis each one gram.* Write out calculated analysis in full, giving in summation every element separately except oxide of tin and silica (as found.) Also state percentage of metallic tin. (Find As, Fe, Cu, S, SiO_2, SnO_2.)

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115. If the atomic weight of iodine were determined as 127, and its vapor, reduced to normal conditions, weighed 11.27 grams per liter, what would be: (1) Molecular weight strictly according to density found. (2) Molecular weight to be inferred by consideration of atomic weight.

116. If we assume weight of one liter of hydrogen as 0.09 gram, what weights of hydrogen are contained in the following gases, *i.e.*, in *one liter of each?*

$$HCl\ ;\ HBr\ ;\ H_2S\ ;\ NH_3\ ;\ CH_4\ ;\ (C_2H_5)\ ;\ C_2H_6$$

117. $$P_4 + 3NaOH + 3H_2O = 3NaH_2PO_2 + PH_3$$

In this reaction if we use ten grams of phosphorus: (1) What weight of NaOH will be consumed? (2) What weight of hypophosphite produced? (3) What volume of phosphine evolved?

118. We have 30 grams of NaOH which is to be made up into a $\frac{1}{10}$ *N.* solution. The NaOH contains $3\frac{1}{2}$ per cent. of impurities.

We have also solution of HCl, of which 10 c.c. precipitate 1.56 grams of AgCl. This is to be made up into a $\frac{1}{10}$ *N.* solution whose volume is to be equal to that of the caustic soda.

(1) What volume shall we have of the NaOH?

(2) What volume of the present HCl solution must be taken for dilution to the same volume as the NaOH solution?

(NOTE.—Use NaOH = 40. AgCl = 143.4. Do not use molecular weight of HCl.)

119. The chloride of a metal contains 33.83 per cent. chlorine. The specific heat of the metal is 0.0308. What is its probable atomic weight?

120. $$MnO_2 + C_2H_2O_4, 2H_2O + H_2SO_4 = MnSO_4 + 4H_2O + 2CO_2$$

5 grams manganese ore yield 4.41 grams CO_2 gas. What per cent. of MnO_2 in the ore?

121. $$4KMnO_4 + 6H_2SO_4 = 2K_2SO_4 + 4MnSO_4 + 6H_2O + 5\ O_2$$

3.69 grams permanganate dissolved in one liter of water. What weight of "available oxygen" will one c.c. of the solution contain?

122. If water absorbs twice its volume of chlorine gas without change of volume: (1) What will be the specific gravity of the solution? (2) How many liters of chlorine are contained in 1000 grams of the solution?

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123. If specific gravity of water is 1, what is specific gravity of air? If specific gravity of air is 1, what is specific gravity of water?

124. If potassium cyanide and sodium cyanide are valued according to their respective percentages of the cyanogen radical, and we have KCy containing 10 per cent. impurity at 22 cents per lb., would it be loss or profit to buy NaCy containing 25 per cent. impurity at the same price? Give exact amount of difference in loss or gain per lb.

125. Into one liter of HCl solution of 1.104 specific gravity are placed 35 grams marble ($CaCO_3$).

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$$

At the close of the reaction there remain 4.39 grams $CaCO_3$. Find: (1) Percentage of HCl by weight in the solution. (2) Weight of calcium chloride produced. (3) Volume of the carbonic acid gas. (4) Volume of the HCl gas.

126. If 1.1486 grams of silver sulphide (Ag_2S) yield 1.000 gram silver, what is the atomic weight of sulphur? (Use exact tabular weights.)

127. One gram of a metal is converted into chloride and precipitated by silver, the AgCl weighs 2.9517. The specific heat of the metal is 0.0324. What is its atomic weight and what is formula of the chloride?

128. One half-gram of crystallized oxalic acid requires 79.36 c.c. permanganate solution for oxidation. What weight of $KMnO_4$ in one liter of solution, and what weight of iron is equivalent to 1 c.c. of the solution?

$$2KMnO_4 + 5(C_2H_2O_4, 2H_2O) + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 18H_2O + 10CO_2$$

$$10FeSO_4 + 2KMnO_4 + 8H_2SO_4 = 5Fe_2(SO_4)_3 + K_2SO_4 + 2MnSO_4 + 8H_2O$$

129. Sulphuric acid is added to 1 liter of ammonia solution, the latter remaining in excess. The ammonia solution is "normal" NH_3. This excess now precipitates ferric hydroxide according to equation:

$$2FeCl_3 + 6NH_4OH = 2Fe(OH)_3 + 6NH_4Cl$$

We have also:

$$2Fe(OH)_3 \text{ (heated)} = Fe_2O_3 + 3H_2O$$

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The Fe_2O_3 weighs 8 grams. Find weight of H_2SO_4. If same had been used to generate hydrogen from zinc, what weight of zinc would have been dissolved and what volume of hydrogen at 16° C. and 740 mm. pressure would have been evolved?

130. When metallic iron is immersed in solution of copper, metallic copper is deposited on the iron, an equivalent weight of iron passing into solution.

$$CuSO_4 + Fe = FeSO_4 + Cu$$

Iron weighed 10 grams. With copper coating, 10.154 grams. Find weight of the copper.

131. $$C_2 + O_2 = 2CO$$

One thousand cubic meters of air are blown through strongly ignited charcoal. Air contains 21 per cent. by volume of oxygen. It goes in at 16° Centigrade, and comes out (as mixture of nitrogen and carbonous oxide gas) at 800° Centigrade. What will be the volume of the gases at exit?

132. Water at zero Centigrade absorbs 1000 times its volume of ammonia gas (NH_3). How many grams of ammonia solution can be made from one liter of water?

What weights of ammonium chloride and of caustic potash, the first pure, the latter 95 per cent. pure, must be used to obtain the ammonia gas for this solution? (Use exact weights.)

$$NH_4Cl + KOH = NH_3 + KCl + H_2O$$

133. A spherical balloon is to be filled with hydrogen and have a "lifting power" of one metric ton. Allowing 14 to 1 as ratio of densities of air and hydrogen, also allowing nothing for displacement of cover and cargo, what will be the size of the sphere? What weights of zinc and sulphuric acid will be required to produce the hydrogen?

134. What will be the "lifting power" of a spherical balloon filled with hydrogen, four meters in diameter. (Ratio as above, 14 to 1.)

135. Into 1 liter of water at zero Centigrade pass 500 liters of HCl gas. Specific gravity is now 1.21, what is total volume of the liquid?

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136. Limestone has the following analysis:

$CaCO_3$	65.00 per cent.
$MgCO_3$	30.00 per cent.
SiO_2	5.00 per cent.
	100.00 per cent.

Wanted, 100 liters CO_2 gas. How many kilos of the limestone and how many kilos of hydrochloric acid 26 per cent. strong must be used?

137. $$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2$$
$$6KOH + 3Cl_2 = 5KCl + KClO_3 + 3H_2O$$

We have MnO_2 85 per cent. pure and are to make 200 lbs. of the chlorate ($KClO_3$), wasting 35 per cent. of the total chlorine in the operation. What weight of the manganese ore must be taken?

138. One gram of a mixture of chlorides of potassium and sodium is converted by heating with sulphuric acid into a mixture of K_2SO_4 and Na_2SO_4. The mixed sulphates weigh 1.1862. What are the percentages of potassium and of sodium chlorides?

139. $$2NaCl + H_2SO_4 = Na_2SO_4 + 2HCl$$

Wanted, 110 lbs. HCl solution 28 per cent. strong. We have salt of 95 per cent. purity, sulphuric acid of 92 per cent. What quantities of each are to be taken?

140. We have common salt 93 per cent. pure, 4 per cent. of the impurity being $MgCl_2$. We have H_2SO_4, 85 per cent. pure. We are to produce 10,000 lbs. HCl solution 22 per cent. 4 per cent. of the Cl in the salt remains in the retorts, and of that evolved as HCl 5 per cent. is lost. Find lbs. of salt, H_2SO_4, and water used.

(In computing H_2SO_4 do not regard unconsumed salt.)

141. The weight of a mineral is 5 grams. Weighed in water, 3.5 grams. Weighed in a certain liquid, 2.8 grams.

Also, a solid, soluble in water, weighs 6 grams. In the above liquid, 1.602 grams. Find specific gravities of the last solid and of the liquid.

142. $$C + S_2 = CS_2$$

Carbon disulphide is formed by passing sulphur over excess of ignited charcoal. We are to produce 100 liters of the liquid, specific gravity 1.27. If 8 per cent. of the sulphur entering the reaction is wasted, and the sulphur used is 95 per cent. pure, what weight must be taken of the same?

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143. An oxy-hydrogen light is to be displayed for five hours, with a consumption of 600 cubic centimeters of the mixed gases per minute. ($H_2 + O = H_2O$.) What quantities of zinc, sulphuric acid and potassium chlorate must be taken to yield the required volumes of hydrogen and oxygen? (Approx. weights.)

Also, it is required to write the two equations of production for these gases so that each one shall be molecularly correct, and at the same time the two equations shall bear the proper actual weight relationship to one another.

144. One liter of water leaves, upon evaporation, residue of 0.8470 gram. The various products of analysis weigh as follows:

For silica, SiO_2	0.1206
For lime, CaO	0.0928
For sodium, $NaCl$	0.3916
For radical SO_3; $BaSO_4$	0.1390
For iron, Fe_2O_3	0.0209
For magnesium, $Mg_2P_2O_7$	0.1769
For chlorine, $AgCl$	0.5220

Write analysis in parts per 100,000, giving compounds and radicals.

(SO_3 to CaO. Cl to Na. All the remaining bases to CO_2.)

145. 90 c.c. of KOH solution neutralize 76 c.c. of HCl acid. Ten c.c. of the latter precipitate 2.1507 grams of silver chloride ($AgCl$).

The two solutions are to be made "normal." How much water must be added to a liter of each respectively?

146. It is required to charge 1000 liters of water with CO_2 gas at ten atmospheres and 14° Centigrade. (Water at one atmosphere absorbs its own volume of the gas at 14°.)

What weights must be taken of limestone 97 per cent. pure, and hydrochloric acid of 22 per cent. HCl gas? What will be the volume of the gas at zero and at 14°?

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$$

147. Analysis of a salt is:

Sodium	16.14 per cent.
Tin	41.75 per cent.
Oxygen	16.84 per cent.
Water	25.26 per cent.
Total	99.99 per cent.

Find its formula.

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148. What is the density of chromyl dichloride, CrO_2Cl_2, referred to air as unity?

149. A gram of silver (10.5) is drawn into wire 0.000006828 meter diameter. What is the length of the wire?

150. A sheet of gold leaf (19.3) is 0.0000001 meter thick. Its area is 5181 square centimeters. What is its weight?

151. $$Na_3AlF_6 + 3H_2SO_4 = Na_3Al(SO_4)_3 + 6HF$$

In this reaction the weight of cryolite taken being enough to yield 42.563 liters of hydrofluoric acid gas at 20° Centigrade, find weight of the cryolite decomposed.

152. Analysis of a chemical compound yields the following figures:

Hydrogen	1.12 per cent.
Sulphur	35.90 per cent.
Oxygen	62.98 per cent.
Total	100.00 per cent.

Find the formula and name the compound. Also find the percentage of water, and re-formulate, separating the water.

153. A mixture of carbonous oxide (CO) and methane (CH_4) is burned, the products of combustion being water and carbon dioxide:

$$CO + O = CO_2, \text{ and } CH_4 + 2\,O_2 = CO_2 + 2H_2O$$

These products being caught, the water in a chloride of calcium tube, the carbon dioxide in a caustic potash bulb, the increases in weight are as below:

For the chloride of calcium tube (water), 0.1609 gram. For the caustic potash bulb (CO_2 gas), 0.3928 gram.

What were original volumes of the two gases? (Call H one-sixteenth of O in this example, and 1 liter of O = 1.43 gram.)

154. The weight of a square sheet of metal, 1 millimeter thick, is 268 grams. Sp. gr. = 6.7. What is length of one side of the square?

155. Light travels 1130 feet per second. How many meters?

156. A cube of wood of sp. gr. 0.8504 weighs 0.62 gram. What is length of one edge of the cube?

157. A cubic meter of sea water contains 12.1 kilograms of sodium (Na). It is combined with chlorine, as NaCl. If the specific gravity of the sea water is 1.026 what percentage of sodium chloride does it contain?

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158. We have 149.7 c.c. of liquid oxygen, sp. gr. 0.89. What will be its volume as gas at 20° Centigrade?

159. Barometer at 29, 30, 31 inches, how many millimeters respectively?

160. Barometer at 780, 770, 760, 750, 740 millimeters, how many inches respectively?

161. $$H_2S + I_2 = 2HI + S$$

We have 16.56 grams of iodine dissolved in one liter of potassium iodide solution. 150 c.c. of this solution require 1.3146 liters of water containing sulphuretted hydrogen to discharge the blue of the starch indicator.

What volume of H_2S gas in one volume of this water?

162. Analysis of a substance:

Mercury	77.52 per cent.
Carbon	18.60 per cent.
Hydrogen	3.88 per cent.
Total	100.00 per cent.

Find empirical and rational formulæ. (Hg = 200.)

163. $$CaSO_4 + 2H_2O = CaSO_4(H_2O)_2$$

This represents the "setting" of plaster of Paris. If we have 500 grams of the dry sulphate, what volume of water must be added?

164. $$CrCl_3 + 2AgNO_3 = Cr(NO_3)_2 + 2AgCl$$

Taking 100 grams of the chromium bichloride, we precipitate 232.56 grams silver chloride. Use atomic weights, Ag = 107.93 and Cl = 35.45. Find atomic weight of chromium, assuming that $CrCl_2$ is correct formula.

165. One half-gram of a metal "M" is converted into sulphide whose formula is known to be M_2S_3. This being oxidized the sulphur is precipitated as $BaSO_4$, whose weight is found to be 1.0402. Find atomic weight of "M." (Use exact tabular at. wts. for Ba and S.)

166.
$$Zn + H_2SO_4 = ZnSO_4 + H_2$$
$$Fe + H_2SO_4 = FeSO_4 + H_2$$
$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

Sulphuric acid of specific gravity 1.320 contains 41.50 per cent. of H_2SO_4. Into one liter of such acid we place, first, 100 grams of zinc, then 200 grams of pure iron. When solution is

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complete we pass in ammonia gas, whose excess measures 350 c.c. (Excess over requirement as shown by last of above equations.)

Find total volume of the gas passed, also, what weights are formed of the various products, viz: zinc sulphate ($ZnSO_4$), ferrous sulphate ($FeSO_4$), and ammonium sulphate $(NH_4)_2SO_4$. Use nearest whole numbers for atomic weights.

167. $P_2 + 5Cl_2 + 8H_2O = 10HCl + 2H_3PO_4$

Take 46 grams of phosphorus in the above reaction.
Find volume of chlorine at zero, also at 20° Centigrade.
Find volumes at same temperatures of hydrochloric acid gas.
Find weight of the ortho-phosphoric acid produced.

168. Formulate from these analyses:

(*a*)	Phosphorus	98.41 per cent.
	Hydrogen	1.59 per cent.
	Total	100.00 per cent.
(*b*)	Silver	65.44 per cent.
	Arsenic	15.15 per cent.
	Sulphur	19.41 per cent.
	Total	100.00 per cent.
(*c*)	Potassium	28.26 per cent.
	Chlorine	25.63 per cent.
	Oxygen	46.11 per cent.
	Total	100.00 per cent.
(*d*)	Silver	85.70 per cent.
	Hydrogen	0.40 per cent.
	Oxygen	6.35 per cent.
	Fluorine	7.55 per cent.
	Total	100.00 per cent.

169. Find percentage composition of the following substances:

(*a*) Hg, NO_3, OH (Mercury basic nitrate).
(*b*) Au_2O_3 $(NH_3)_4$ (Fulminating gold).
(*c*) $Pb(CH_3)_4$ (Lead methyl).
(*d*) $SnCl_4$, $2NH_4Cl$ (Stannic-ammonium chloride).

170. Liquid hydrogen has specific gravity 0.07.
What is the volume of one gram?
How many times that volume will it occupy as gas at 100° C.?
The boiling point is −397.3° F., what is it in Centigrade?

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171. Air weighs 1.293 gram per *liter*, and contains 23.3 per cent. oxygen by weight. How many *pounds* of oxygen are consumed in twenty-four hours by a man who inhales 18 *cubic feet* per hour?

172. One hundred grams of refined copper being taken for analysis, the following weights are obtained:

For iron; Fe_2O_3..... 0.0229 gram.
For arsenic; Ag (from Ag_3AsO_4)..... 0.0432 gram.
For lead; $PbSO_4$..... 0.0263 gram.

Calculate the analysis—copper by difference.

173. The area of the earth's surface being assumed as 196,662,892 square *miles*, and atmospheric pressure as 1.0333 *kilograms per square centimeter*.

Assume that carbon dioxide forms 0.04 (four one-hundredths of one per cent.) of the *weight* of the atmosphere, and find:

1. Mass of the carbon in atmosphere in metric tons.
2. Volume of the carbonic acid gas in cubic meters.

174. $CaCO_3 + 2HCl = CaCl_2 + 2H_2O + CO_2$

We take 50 grams $CaCO_3$ and form 72.8 grams $CaCl_2$. (1) What per cent. and what weight of $CaCO_3$ remain unacted on? (2) What weight used of a 15 per cent. sol. of HCl? (3) What vol. of HCl gas?

175. It is supposed that about ten million million tons of limestone ($CaCO_3$) are available for quarrying, the world over. Suppose all of its carbon dioxide to be released, and ultimately returned to the earth as carbon, in the shape of coal.

If this coal weighs 80 lbs. to the cubic foot, and contains 80 per cent. total carbon, what will be its tonnage?

2. If it is deposited in a bed ten feet thick, what will be the area in square miles of the coal field?

176. $2HNO_3 + P_2O_5 = 2HPO_3 + N_2O_5$

Nitric acid with phosphoric anhydride produces meta-phosphoric acid and nitric anhydride. We take 100 cubic centimeters of the nitric acid, and produce 130.378 grams of the nitric anhydride (N_2O_5).

1. What weight of the phosphoric anhydride is acted on?
2. What is the specific gravity of the nitric acid?

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177. A spherical pellet of sodium, sp. gr. = 0.97, is plunged under water contained in an inverted cylinder whose diameter is 2 centimeters. The hydrogen marks a corrected displacement of column one meter long.

$$Na_2 + 2H_2O = 2NaOH + H_2$$

Find weight and volume of the hydrogen.

Find weight and volume of the sodium, also radius of the pellet.

Find weight of the caustic soda, NaOH, formed.

178 $$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2$$
$$Cl_2 + 2KI = 2KCl + I_2$$

0.84 gram impure MnO_2 sets free chlorine enough to liberate 1.89 grams iodine. What is the per cent. of actual MnO_2 in the ore, and what volume of chlorine is evolved?

179. $$2FeCl_3 + 2H_2O + SO_2 = 2FeCl_2 + 2HCl + H_2SO_4$$

The volume of SO_2 gas involved in this reaction is 11.362 liters. What weight of metallic iron is involved?

180. Taking one-gram portions of a mixed ore for analysis, the various elements are determined from the following analytical products:

For sulphur.....	weight of $BaSO_4$	= 0.9461 gram.
For iron.....	weight of Fe_2O_3	= 0.1468 gram.
For lead.....	weight of $PbSO_4$	= 0.1073 gram.
For zinc.....	weight of ZnO	= 0.1352 gram.
For lime.....	weight of CaO	= 0.1141 gram.
For silica.....	weight of SiO_2	= 0.3618 gram.

Assume that the lime is present as carbonate ($CaCO_3$) and adjust the other elements as follows: Compute lead and zinc as sulphides, then apportion all the remaining sulphur to iron as FeS_2. Calculate the remaining iron as Fe_2O_3. Make two statements, one a summation by elements Fe, Pb, Zn, S and O (with Fe_2O_3), adding the oxides SiO_2, CaO and CO_2; the other a summation by "proximates," viz: SiO_2, FeS_2, PbS, ZnS, Fe_2O_3, $CaCO_3$.

181. 1.339 grams carbon make what volume CO_2 gas at 20° Centigrade? Also, what volume of CO gas at the same temperature?

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182. A metal of specific gravity 8.013 is weighed in a liquid of specific gravity 0.7024 giving an "apparent" weight of 7 grams. It is now weighed in a heavier liquid showing "apparent" weight of 6.2122 grams. What is the specific gravity of the heavier liquid?

183. 0.750 gram of an iron ore is dissolved and reduced. Being now "titrated" with $KMnO_4$ solution, it requires 30 c.c. of a solution of which 1 c.c. $\equiv$ 0.0166 metallic iron. What is the percentage of iron?

184. 1 c.c. of $Ba(OH)_2$ solution is neutralized by 1.226 c.c. of a solution of oxalic acid.

1 c.c. of this oxalic solution neutralizes 0.007 gram of caustic soda (NaOH). What weight of $BaSO_4$ will one c.c. of the solution of $Ba(OH)_2$ precipitate? (Do not use the molecular weight of oxalic acid in the calculation.)

$$\begin{aligned} Ba(OH)_2 + H_2C_2O_4 &= BaC_2O_4 + 2H_2O \\ 2NaOH + H_2C_2O_4 &= Na_2C_2O_4 + 2H_2O \\ Ba(OH)_2 + H_2SO_4 &= BaSO_4 + 2H_2O \end{aligned}$$

185. From one hundred pounds of potassium chlorate, how many cubic feet of oxygen will be evolved?

$$2KClO_3 = 2KCl + 3\ O_2$$

186. An undiscovered metal, "X," has a sulphate "XSO_4" of which it forms 51.02 per cent. What is its atomic weight?

187. What weights of (*a*) MgO, (*b*) NaOH, (*c*) Zn, (*d*) $CaCO_3$, will 100 c.c. of normal acid dissolve?

188. We have a new metal and an oxide of same of which we know only that the metal is sixty per cent. of the oxide.

Under the various assumed formulæ X_2O, XO, X_2O_3, XO_2, find the resulting atomic weights for "X."

189. One liter of a compound gas at 700 mm. pressure and 20° Centigrade temperature weighs 4 grams. What is its molecular weight?

190. $$SnCl_2 + 2HCl + I_2 = SnCl_4 + 2HI$$

We have a solution of iodine in KI containing ten grams of iodine to the liter of solution. Using one gram of tin ore for analysis, we consume 67 c.c. of the iodine solution. What per cent. of tin in the ore?

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191. If 230 c.c. of normal acid act on zinc, what weight of the metal will be dissolved, and what volume of hydrogen gas at 10° will be evolved?

$$Zn + 2HCl = ZnCl_2 + H_2$$

192. 100 c.c. of HCl neutralize 88 c.c. of NH_3 solution. Also, 100 c.c. of the same HCl precipitate 3.2 grams AgCl. Taking 0.5 gram of a substance for nitrogen determination, pass NH_3 from same into 50 c.c. of the HCl, then it takes 35 c.c. of the NH_3 to neutralize excess. Find per cent. of nitrogen.

193. $$CuSO_4 + Fe = FeSO_4 + Cu$$

When a piece of metallic iron is immersed in a copper solution the iron goes into solution, leaving metallic copper adhering to the remaining iron.

A piece of iron weighing 10 grams weighs 10.1 grams after immersion in the copper solution, what is weight of the copper? (Fe = 56; Cu = 64.)

194. 100 c.c. of mixed gases, viz: CH_4 = 40 c.c., C_2H_4 = 15 c.c., C_2H_2 = 5 c.c., CO = 15 c.c. and H_2 = 25 c.c., are burnt in oxygen, equations as below:

$$\begin{aligned} CH_4 + 2\,O_2 &= CO_2 + 2H_2O \\ C_2H_2 + 5\,O &= 2CO_2 + H_2O \\ C_2H_4 + 3\,O_2 &= 2CO_2 + 2H_2O \\ CO + O &= CO_2 \\ H_2 + O &= H_2O \end{aligned}$$

Required volume of oxygen used, also volumes of CO_2 and H_2O produced, taking the latter two at 100° Centigrade.

195. We have 100 c.c. of a mixture of CO_2, CO and H_2. The mixed gases are passed through $Ba(OH)_2$:

$$Ba(OH)_2 + CO_2 = BaCO_3 + H_2O$$

The precipitated $BaCO_3$ weighs 0.176 gram. The residual gas is burned:

$$CO + O = CO_2 \text{ and } H_2 + O = H_2O$$

Products of combustion passed through $CaCl_2$ tube and KOH tube:

$$CaCl_2 + H_2O = CaCl_2, H_2O \text{ and } 2KOH + CO_2 = K_2CO_3 + H_2O$$

$CaCl_2$ tube before operation weighed 38.3388, after same weighed 38.3667.

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KOH tube before operation weighed 42.8244, after same weighed 42.9128.

From these experimental data find the analysis by volume of mixture.

196. A mixture of AgCl and AgBr weighs 0.3690 gram. The metallic silver from same weighs 0.2558 gram.

Find weights of AgCl and AgBr. Also find weight of silver in the chloride and in the bromide, and separate weights of chlorine and bromine.

(*Suggestion.*—Let x and y represent weights of silver in the chloride and bromide respectively. It will now be easy to find expressions for AgCl and AgBr, using the atomic weights or a relation of them as coefficients for the unknown quantities.)

197. One gram of an organic substance being taken for analysis, its nitrogen is converted into ammonia (NH_3), which is neutralized by 42.75 c.c. of decinormal acid. What per cent. of nitrogen in the substance?

198. A precipitate of mixed bromide and iodide of silver weighs 0.939 gram; being converted into silver chloride, weighs 0.637 gram. Find weights of the bromide and iodide of silver, separately.

199. A limestone has following composition:

CaO	52.64 per cent.
CO_2	41.36 per cent.
SiO_2	6.00 per cent.
Total	100.00 per cent.

When this is "burned" at proper heat all the lime remains as CaO, but if "overburned" there is formed $2CaO, 3SiO_2$.

If 1000 kilos (1 metric ton) is burned, find volume of CO_2 gas evolved. Also, weights of water required for slaking: (1) if well burned, (2) if overburned.

200. How much sodium chloride must be dissolved in 1 liter of water if 1 c.c. of the solution is to precipitate 0.01 gram of silver?

$$NaCl + AgNO_3 = AgCl + NaNO_3$$

201. In a cubic meter of marble (sp. gr. = 2.7) how many cubic meters of CO_2 gas, if liberated?

In a cubic meter of water how many cubic meters of hydrogen? (Take $CaCO_3 = 100$; $H_2O = 18$.)

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202. A solid weighing 10.874 grams displaces 3.593 grams of benzene, whose sp. gr. is 0.8886. Find sp. gr. of the solid.

203. What weights of potassium permanganate and of potassium dichromate, respectively, will convert 1 gram of iron from ferrous to ferric condition?

$$10FeSO_4 + 2KMnO_4 + 8H_2SO_4 = 5Fe_2(SO_4)_3 + K_2SO_4 + 2MnSO_4 + 8H_2O$$
$$6FeSO_4 + K_2Cr_2O_7 + 7H_2SO_4 = 3Fe_2(SO_4)_3 + K_2SO_4 + Cr_2(SO_4)_3 + 7H_2O$$

204. In taking an "assay ton" of gold ore, for assay, we make an error in weighing of one milligram. If the true assay value of the ore is one hundred dollars per ton, and the work is perfect, what error in the valuation is introduced by the error in "weighing in?"

205. If ore were weighed with absolute accuracy, what error in the weighing of the "button" would introduce the same error in valuation of the ore as the 1 milligram error in "weighing in" the ore? (Some data as to weight taken and true value as in 204.)

206. What is the weight of one liter of air, at 17° Centigrade and 800 mm. barometer?

207. A sealed flask holds one gram of hydrogen gas. Capacity of flask one liter. What is the pressure at 20° Centigrade?

208. We have a compound of potassium, chlorine and oxygen which loses all its oxygen when heated. One gram of it thus treated loses 0.4609 gram oxygen. The residue is dissolved and poured into silver nitrate solution, precipitating silver chloride, the silver in which weighs 0.7749 gram.

Another one-gram portion is treated with sulphuric acid, and yields 0.6351 gram of K_2SO_4. Find formula.

209. 1.357 grams alcohol dissolved in benzene depress the freezing point 1.448° Centigrade. Find approximate molecular weight of alcohol.

210. 5.45 grams phosphorus dissolved in 100 grams carbon disulphide raise the boiling point 1° Centigrade. Find approximate molecular weight. (In 209, K = 50. In 210, L = 23.7.)

211. $$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2$$

Wanted 690 pounds chlorine. How many pounds of manganese dioxide of 85 per cent. MnO_2 must we take, and what will be volume in cubic feet of the chlorine?

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212. One liter of chlorine at 35° C. weighs 3.020 grams. What is the pressure in millimeters?

213. $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

One gram $Ca(OH)_2$ in solution. Add 630 c.c. CO_2 gas. Which is in excess, and by what weight?

214. A certain weight of ammonium chloride (NH_4Cl) being decomposed into its elements, the gases in toto measure 131.1275 liters, at 800 mm. and 27° C. What weight of the salt was used?

215. $CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$

The CO_2 gas in this reaction measures 100 liters at 27.3° C., and 836 mm. pressure. What was weight of the $CaCO_3$ taken? What was volume of the HCl gas, and what was its weight?

216. $S_2 + 3O_2 + 2H_2O = 2H_2SO_4$

and $4FeS_2 + 15O_2 + 8H_2O = 2Fe_2O_3 + 8H_2SO_4$

Suppose sulphur, 97 per cent. pure, costs twice as much as pyrites, 91 per cent. pure, which process for the manufacture of sulphuric acid would be the cheaper, assuming that all expenses and losses balance?

217. What is the formula for HNO_3 which contains 70 per cent. acid and 30 per cent. water. (Sp. gr., 1.44.)

218. A cylinder one half-meter in diameter and one meter high, is filled with oxygen at 15° C., which suffices to burn 131.285 grams of carbon. What was the pressure of the gas in the cylinder ($C + O_2 = CO_2$)?

219. Analysis of mineral water. One liter of the water gives a residue weighing 2.4176 grams. The products weighed (in analysis) are as follows:

For CaO.....	CaO	weighs.....	0.05912 gram.
For SO_3.....	$BaSO_4$	weighs.....	0.05516 gram.
For Cl.....	AgCl	weighs.....	5.5601 grams.
For Na.....	NaCl	weighs.....	2.2868 grams.
For Mg.....	$Mg_2P_2O_7$	weighs.....	0.02465 gram.
For CO_2.....	CO_2	weighs.....	0.05332 gram.
For oxygen, by calculation		weighs.....	0.0063 gram.

"Adjudication" to be made as follows: (1) All SO_3 to CaO. (2) Excess of CaO to CO_2. (3) All Mg to Cl. (4) Excess of

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Cl to Na. (5) Excess of Na to CO_2 (as Na_2CO_3). *Use approximate atomic weights only.* This includes Ba and Ag. Direct calculations only. No "factors."

It is required to state the parts per 100,000 of the following salts, as calculated, also the parts of the "proximates" as below, viz: Calcium sulphate, calcium carbonate, magnesium chloride, sodium carbonate, sodium chloride (salts). Also calcium oxide, chlorine, sulphuric anyhydride radical (SO_3), sodium, magnesium, carbon dioxide, oxygen (in Na_2CO_3), *i.e.*, the oxygen other than that in CO_2.

These must check with original residue, making for every summation the 2.4176 grams, or 241.76 parts per 100,000.

220. A sphere of silver is 2 cm. in diameter. A cylinder of silver is 2 cm. in diameter and 2 cm. high. A cube of the same metal is 2 cm. edge. Find weight of each of these. (Sp. gr. of silver = 10.5.)

221. Into dilute sulphuric acid, which contains 30 grams of actual H_2SO_4, we pass 10 liters ammonia gas at 16° C. and normal pressure. What weight of zinc will the acid still dissolve?

What is weight of the ammonia gas? Of the residual H_2SO_4?

$$H_2SO_4 + 2NH_3 = (NH_4)_2SO_4. \quad \text{Also } Zn + H_2SO_4 = ZnSO_4 + H_2$$

222. Potassium (sp. gr. = 0.86) absorbs 126 times its volume of hydrogen. Formulate the alloy thus formed.

223. If a solution of NaOH contains 12 grams in one liter, how many c.c. of this solution will be neutralized by 100 c.c. of a HCl solution, of which one liter neutralizes 10 grams of calcium carbonate ($CaCO_3$)?

224. One c.c. of a solution of $AgNO_3$ precipitates 0.005 gram NaCl. Taking 1 gram of a soluble substance for analysis, we use 40 c.c. of this solution. What is percentage of chlorine?

225. One gram of a triple alloy of copper, tin and zinc is taken for analysis. The products weighed are Cu_2S, SnO_2, and ZnS. Weights as follows: $Cu_2S = 0.7512$; $SnO_2 = 0.1269$; $ZnS = 0.4471$. Deduce analysis.

226. Ten grams of steel are taken for analysis for sulphur, phosphorus, silicon and manganese. Gravimetric products weigh as follows: $BaSO_4 = 0.0402$; $Mg_2P_2O_7 = 0.0213$; $SiO_2 = 0.0418$; $Mn_2P_2O_7 = 0.0884$. Deduce analysis.

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227. If 820 c.c. of gas at 10° C. and 740 mm. pressure weigh 1.265 grams, what is molecular weight of the gas?

228. $3Fe + 2O = Fe_2O_3$

Combustion of iron. One gram of iron is burned in one liter of air, what was the temperature of the air, pressure normal?

229. Wanted one liter of sulphuric acid of which 100 c.c. are equivalent to 0.1 gram ammonia (NH_3). We have sulphuric acid of which 100 c.c. precipitate 0.699 gram $BaSO_4$. How many c.c. of this acid and how many of water must be taken for the required liter of acid?

230. One hundred liters of coal gas are burned in air. Composition of the gas by volume is as below, oxygen in air 21 per cent. by volume. Water being condensed out, find volume, weight and density of the resulting mixture of nitrogen and carbon dioxide.

CH_4 = 40	$CH_4 + 2O_2 = CO_2 + 2H_2O$
C_2H_4 = 4	$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$
CO = 10	$2CO + O_2 = 2CO_2$
H_2 = 46	$2H_2 + O_2 = 2H_2O$
100	

Separate nitrogen and carbon dioxide in answering.

231. We have an indefinite amount of a solution of potassium permanganate, of which 100 c.c. are equivalent to 1.07 grams iron. Take the three equations:

$$10FeSO_4 + 2KMnO_4 + 8H_2SO_4 = K_2SO_4 + 2MnSO_4 + 8H_2O + 5Fe_2(SO_4)_3$$
$$5H_2SO_3 + 2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 3H_2O + 5H_2SO_4$$
$$5H_2C_2O_4 + 2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 10CO_2 + 8H_2O$$

We want to get one liter of solution of which 100 c.c. shall ≡ 1 gram iron. Another liter of which 100 c.c. shall ≡ to 0.5 gram SO_2. A third liter of which 100 c.c. shall ≡ to 0.5 gram $H_2C_2O_4$. What volumes respectively must be taken of the permanganate solution? Also, if we start in each case with one liter of the permanganate solution, how much water must be added to each liter for each of the three requirements?

232. What weight of mercuric sulphide yields a quantity of mercury such that it requires the oxygen from 6.66 grams of water to form mercuric oxide?

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233. We take 1.75 grams of an organic substance and derive from it 22.8 c.c. nitrogen gas at 15° C. and 720 mm. pressure. What percentage of nitrogen?

234. 295.456 grams of a hydrocarbon give 509.091 liters of carbon dioxide when burned. This same weight vaporized and calculated back to 0° and 760 mm., gives 84.8489 liters. Find formula.

(N.B.—One of these conditions will solve the problem without the use of the other. Which one? Why is the other insufficient of itself?)

235. A spherical balloon whose radius is ten meters is filled with hydrogen gas, whose weight is taken as 0.09 gram per liter. What is the size of the sphere of lead (sp. gr. = 11.37) which will weigh the same as the hydrogen?

236. The formula of diazobenzene bromide is $C_6H_5N_2Br$. Its analysis is: C = 38.92; H = 2.70; N = 15.13; Br = 43.24 (100 per cent.).

Find weights of the following products of analysis, one gram of the substance having been taken:

For carbon, CO_2; for hydrogen, H_2O; for nitrogen, Pt (from $(NH_4)_2\ PtCl_6$); for bromine, AgBr.

237. A sphere of magnesium is dissolved in HCl ($Mg + 2HCl = MgCl_2 + H_2$). The hydrogen evolved measured 23.148 liters at 18° C. and 700 mm.

What weight of magnesium? What was radius of the sphere, and its volume? (Take sp. gr. of magnesium at 1.74; its atomic weight at 24.4; atomic weight of hydrogen at 1.008, its weight per liter at 0.09 gram.)

238. One gram naphthaline dissolved in 17.2 c.c. of chloroform raises boiling point 1.2° C. Find approximate molecular weight.

239. One gram organic material gave 1.433 CO_2 and 0.1959 H_2O by weight. Also, one gram gave 121.4 c.c. of nitrogen (0° and 760 mm). Find analysis and formula (oxygen by difference).

240. $4KCy + 2Au + H_2O + O = 2KOH + 2KAuCy_2$

What volume of air must be taken up for each ounce of gold in solution? (Cyanide process for gold.) Take one oz. troy = 31.1 grams. Oxygen in air, 21 per cent. by volume. Take at. wt. of gold as 196.6. (Give wt. and vol. of oxygen, liters and cu. ft. of air.)

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241. A chloride solution of a metal is precipitated by silver nitrate. Wt. of AgCl = 1.6679 grams. What is at. wt. of metal if a dyad? If a triad?

242. $2KMnO_4 + 5H_2C_2O_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 10CO_2 + 8H_2O$

We use 15 grams impure $KMnO_4$ and obtain 10 liters CO_2. What is per cent. of impurity in the permanganate?

243. $MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2$

Manganese dioxide is 82 per cent. pure, HCl solution contains 20 per cent. HCl. Sp. gr. of the acid is 1.1. We want 100 liters of chlorine at 15° C. and 650 mm. pressure. Give weights of MnO_2 and HCl solution, also volume of latter.

244. $CaOCl_2 + H_2SO_4 = CaSO_4 + H_2O + Cl_2$
$2Au + 3Cl_2 = 2AuCl_3$

One kilogram of bleaching powder yields 140 liters chlorine gas. What per cent. of "available" chlorine does the powder contain by weight, and what weight of gold will be dissolved by the chlorine evolved?

245. What volume of hydrochloric acid gas (HCl) will, when in solution, dissolve one kilometer of iron wire containing 0.4 per cent. of insoluble impurities. Diameter of the wire 0.2 millimeters. Sp. gr. = 7.8. (Atomic weight of iron = 55.9. Cl = 35.45, and H = 1.008.) Use the "22.4 "rule. Assume 10° Centigrade and 670 mm. pressure for the HCl.

$$Fe + 2HCl = FeCl_2 + H_2$$

246. A certain quantity of sulphuric acid (98) will dissolve one pound of an alloy containing equal weights of zinc (65) and cadmium (112). The same quantity of this acid is allowed to act on one pound of iron (56).

What weight of iron remains unacted on? What weight of actual H_2SO_4 is required for the alloy, and what is the deficit in the case of the iron?

247. Assuming that silver is acted upon by nitric acid according to the equation:

$$3Ag + 4HNO_3 = 3AgNO_3 + 2H_2O + NO$$

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Take sp. gr. of silver as 10.5 and that of ice as 0.92. We have 98 c.c. of silver, what volume of ice will be produced by freezing the water from this reaction?

248. A metal dissolves in sulphuric acid:

$$M + H_2SO_4 = MSO_4 + H_2$$

In this reaction, 100 grams of the metal yield 100 liters of hydrogen gas.

Find atomic weight of the metal, using H = 1 and crith = 0.0896 gram.

249. A certain weight of a dyad metal "M" yields 0.2900 gram of oxide, MO, and 0.4273 gram of chloride, MCl_2. Find atomic weight of the metal. (Use the 1911 atomic weights from Table I.)

250. The atomic weights of two metals are in the ratio 3 to 5. The molecular weights of their oxides are as 5 to 7. Assuming that these metals are dyad (oxide = MO), find their atomic weights.

251. A cylinder, 6 meters altitude and 2 meters diameter, contains acetylene gas enough to keep 100 burners at ½ cubic foot each, per hour, for 100 hours. What is the pressure in millimeters, and what is the weight (metric) of the gas?

252. $$CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O$$

The CO_2 gas obtained by this reaction is charged into a cylinder 7 meters altitude and 2.2 meters diameter. Temperature of the gas 15° C., and pressure 2760 mm. The HCl solution used is of sp. gr. 1.17 and contains 33.46 per cent. HCl gas by weight. What volume of this solution was used?

253. Sulphuric acid containing 63 per cent. H_2SO_4 has sp. gr. 1.535.

Sodium carbonate solution containing 9 per cent. Na_2CO_3 has sp. gr. 1.095.

Ammonia solution containing 25 per cent. NH_3 has sp. gr. 0.91.

Into 100 c.c. of the carbonate solution, pour 10 c.c. of the acid. How many c.c. of the ammonia solution must now be used to neutralize? (Use "nearest" atomic weights.)

$$Na_2CO_3 + H_2SO_4 = Na_2SO_4 + H_2O + CO_2$$
$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

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254. One liter of ammonia solution (sp. gr. 0.91) contains 25 per cent. NH_3 by weight. Add HCl solution (sp. gr. 1.1) containing 20 per cent. HCl, to exact neutrality. Add caustic soda solution in exact proportion by equation below. The caustic soda solution contains 9 per cent. NaOH and has sp. gr. 1.17.

What volumes of the acid and alkaline solutions are used respectively?

$$NH_3 + HCl = NH_4Cl$$
$$NH_4Cl + NaOH = NaCl + NH_3 + H_2O$$

255. A ton of lead ore assays 6.95 per cent. lead. It is separated by concentration into "heads, middles and tails" weighing and assaying respectively as below:

Heads.....	160 lbs.	assaying 65 per cent. lead.
Middles.....	110 lbs.	assaying 12 per cent. lead.
Tails.....	1730 lbs.	assaying 1 per cent. lead.
Total.....	2000 lbs.	

These results do not check with the weight and assay of the original ore.

1. Find amount of the discrepancy.

2. Assuming that the error lies wholly in the assay of the "tails," find what that assay should be, to reconcile results on products with original.

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ANSWERS TO MISCELLANEOUS PROBLEMS.

1. Silver, 54.124. Copper 45.876. Total 100 grams.
2. 357.12 grams.
3. CH_4. Two liters.
4. 34.42 cubic centimeters.
5. 0.7727 liters.
6. 3822° Centigrade.
7. 9.266+ millimeters.
8. 18.58 per cent.
9. 0.001 per cent. (One-thousandth of one per cent.)
10. 207.1.
11. 1.435 ton = 2870 lbs.
12. 0.6155 grams.
13. 117.1° C.
14. Original volume of CO = 18.6, of H_2 = 27.9 c.c. Volume of oxygen added = 40 c.c.
15. 7.437 grams.
16. 55.
17. 0.006 gram.
18. Weight = 1.359 grams. Volume = 892 c.c.
19. Formula Al_2Cl_6. Wt. of 1 liter, 11.93 grams.
20. Excess in weight, 41.2 grams. In volume, 54.28 liters.
21. NaCl in excess 0.59 gram.
22. 2.8 grams.
23. 3.94 grams.
24. 172.8 grams.
25. At. wt. = 7.
26. 974.66 c.c.
27. 12.998 meters.
28. Sp. gr. = 2.486.
29. One-fourth.
30. 1.2910 grams.
31. At. wt. = 65.
32. At. wt. = 19.
33. Excess of FeS = 0.102 lb.
34. Zinc excess = 0.01 lb.
35. NH_3 excess 0.669 gram in weight, and 878 c.c. in volume. HCl def. 1.43 grams in weight, and 872 c.c. in volume.

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36. H_2SO_4 excess = 0.76+ gram. NH_3 deficit = 0.264 gram.
37. 68+ tons.
38. 200 liters.
39. 29.72 c.c.
40. CO_2 gas to air as 2 to 3.
41.

Silica	7.31 per cent.
Alumina	2.46 per cent.
Ferric oxide	85.00 per cent.
Manganous oxide (MnO)	2.56 per cent.
Magnesia (MgO)	1.60 per cent.
Water	1.03 per cent.
Total	99.96 per cent.

Loss 0.04 per cent. Metallic iron = 59.45 per cent.

42. Atomic weight = 65.
43. Assay = 7.38 oz. to ton.
44. Gold = 24 oz. to ton. Silver = 650 oz. to ton.
45. Weight of salt, 64.1 kilograms.
46. 48,667 lbs.
47. The answer is the square root of the product of the two weights. In this instance the square root is nearly the same as the mean of the two numbers, viz: 10.65.
48. $2 \times 2.5 = 5$. Square root of 5 = 2.236+.
49. The C_6H_6 must be considered as reduced to its vapor volume. We then have: C_6H_6 = 13.2 liters. O_2 = 99 liters. CO_2 = 79.2 liters.
50. Mercury being at 76 cm., water stands at 1033.296 cm.; alcohol stands at 1275.674 cm.; acid stands at 558.535 cm.
51. Weight = 1.149 grams.
52. Assay, 6 oz. to ton.
53. Assay, 0.47 oz. to ton.
54. Assay before drying 51 per cent.
55. Assay of "charge" = 45.45 per cent.
56. Formula, C_6H_6.
57. Formula of the "ferric" salt;

$$(NH_4)_2SO_4, Fe_2(SO_4)_3 + 14H_2O$$

Formula of the "ferrous" salt:

$$(NH_4)_2SO_4, FeSO_4 + 6H_2O$$

58. Assay of the mixture, 85 ounces.
59. Precipitate weighs 8.51 grams.

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60. The silver is in excess by 0.36 gram.
61. Weight = 1.323 grams.
62. Hydrogen = 12.4 liters. Oxygen = 6.2 liters.
63. Zinc = 26.78 kilos.
64. Volume is 479 times that of the liquid.
65. Assays "dry" 56 ounces.
66. 20,322 $\frac{58}{100}$ lbs.
67. The "wet" assay would be represented by $\frac{(100-a)\times b}{100}$.
68. Take 281.7 lbs. of No. 2.
69. FeS_2 58.31 tons.

70.

ANALYSIS BY SALTS.		ANALYSIS BY RADICALS.	
$CaSO_4$	37.43	Chlorine	32.72
$CaCO_3$	3.21	SO_3	22.01
$MgCl_2$	18.00	Mg	4.60
NaCl	21.82	CaO	17.22
KCl	12.78	K	6.70
		Na	8.58
	93.24		91.83
Parts in 100,000.		CO_2 required	1.41
			93.24

71. Three atmospheres.
72. Carbon = 1.25 per cent.
73. Take for analysis 2.7838 grams.
Example.—Take 2.7838 grams, find weight of $Mg_2P_2O_7$ = 0.0215. Then per cent. of phosphorus is 0.215.
74. Assay is 104.95 ounces.
75. Volume = 2.976 liters.
76. Weight of the acid = 9.8 grams.
77. At. wt. of "M" = 23.
78. Take 124.87 grams.
79. Gold, 24.75 oz. to ton. Silver, 219.3 oz. to ton.
80. 52 per cent.
81. 899° C.
82. Volume of the gas = 2.50 liters.
83. Since gaseous molecules occupy equal volumes, the equations shown in the question indicate the answer. The dissociated gases are respectively twice the volumes of the original substances. For example: $H_2SO_4 = H_2O + SO_3$. We have 2 liters of density 18, and 2 liters of density 80. Thus the density becomes $\frac{98}{2}$ instead of 98.

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84. 5.4202 grams in 1 liter.
85. At. wt. = 63.
86. (*a*) Density of the mixture 37.45. (*b*) Volume of permanent gas, 2.96 liters.
87. At 1175+ millimeters.
88. 60.44 c.c., at the new p. and t.
89. 91° C. $\left(V' = 1.33 \div 1 + \frac{t}{273}\right)$
90. Sp. gr. = 1.75.
91. Crucible, 13.0302 grams. CaO = 0.1736 grams.
92. Sp. gr. of mineral = 5.
93. First ore 3.4 tons. Second ore 6.8 tons.
94. They must be taken, as to weight, in the ratio of their respective specific gravities, which is the same as to say that they must be taken in equal bulk.
Example.—Gold, sp. gr. 19.3; silver, sp. gr. 10.5. If we take 19.3 grams of gold and 10.5 grams of silver we shall evidently have one cubic centimeter of each, and sp. gr. of the alloy would be $\frac{19.3 + 10.5}{2} = 14.9$.
95. One-fourth of an atmosphere.
96. H_2S gas, 10 c.c. in one liter. Solid constituents as below:

CaO	8.735	CaO	8.735	$CaSO_4$	21.20
SO_3 with the above	12.465	Mg	6.660	Na_2SO_4	28.14
Na_2O	12.280	Na	54.720	NaCl	115.96
SO_3 with the above	15.860	SO_3	28.330	$MgCl_2$	26.08
Na (in NaCl)	45.620	Cl	89.760		
Cl with the above	70.340	O*	3.175		
Mg	6.660				
Cl_2 with the above	19.420				
	191.380		191.380		191.38

Note that NaCl as determined in the analysis does not indicate the actual NaCl in the water, but is necessarily greater.

97. Half an atmosphere.
98. Atomic weight = 23.6.
99. Density of mixture = 12. Density of steam 18.

*With the Na_2O in Na_2O, SO_3, otherwise Na_2SO_4.

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100. Complete analysis as below:

Silica	8.05 per cent.	Zinc in ZnS	15.28
Ferric oxide	12.70 per cent.	Zinc in $ZnSO_4$	18.88
Zinc sulphide	22.72 per cent.	Zinc in ZnO	8.03
Zinc sulphate	46.49 per cent.	Total zinc	42.19
Zinc oxide	9.98 per cent.		
	99.94 per cent.	Metallic iron	8.88
Loss	0.06 per cent.	Total sulphur	16.66
Total	100.00 per cent.	Total SO_3	23.01
		Oxygen in ZnO	1.95
Sulphur in ZnS	7.44 per cent.	Oxygen in Fe_2O_3	3.82
Sulphur in SO_3	9.22 per cent.		

101. Atomic weight = 55.
102. Sp. gr. of the acid = 1.162.
103. Atomic weight = 55.
104. 7.143 liters air. 1.5 liters oxygen.
105. 2612 liters.
106. Sp. gr. = 2.5.
107. (*a*) Density of mix. = 49.5. (*b*) Den. of $COCl_2$ = 99. (*c*) Each 3 liters.
108. Weight deficit = 2.7+ grams.
109. MnO_2 required, 22.35 grams. Weight of air, 35.74 grams.
110. (1) 0.3707. (2) 2.698.
111. For CO, $\frac{1}{2}$. CH_4, 2. C_2H_4, 3. C_2H_2, $2\frac{1}{2}$. H_2S, $1\frac{1}{2}$. PH_3, 2 liters.
112. Wt. of KOH = 0.2808 gram.
113. Wt. of excess oxygen, 4.287 grams. Volume, 3 liters. Original volumes: oxygen, 7 liters; CO, 8 liters.
114. Analysis by elements, etc.

Silica	46.27 per cent.
Stannic oxide	8.24 per cent.
Arsenic	3.66 per cent.
Sulphur	18.93 per cent.
Copper	4.26 per cent.
Iron	18.35 per cent.
Total	99.71 per cent.
Loss	.29 per cent.

Metallic tin = 6.49 per cent.

115. (1) 252.45. (2) 254.

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116. In HCl, 0.045. In HBr, 0.045. In H_2S, 0.09. In NH_3, 0.135. In CH_4, 0.18. In (C_2H_5), 0.225. In C_2H_6, 0.27.
117. (1) 9.67 grams. (2) 21.29 grams. (3) 1.806 liters.
118. (1) NaOH made up to 7.2375 liters. (2) Take 0.6653 of HCl solution.
119. Trial figure by analysis found by 33.83 : 66.17 = 35.45: 69.34. But if we now multiply by the specific heat, $69.34 \times 0.0308 = 2.13+$. This figure (2.13) is about $\frac{1}{3}$ of the average constant under the law of Dulong and Petit. We therefore take $69.34 \times 3 = 208$ as atomic weight.
120. 87.2 per cent. of MnO_2.
121. 0.0009342 gram.
122. (1) Sp. gr. = 1.00634. (2) 1.987 liter.
123. (1) Sp. gr. of air = 0.001293. Sp. gr. of water = 773.
124. Gain of 2.3 cents per lb., *i.e.*, NaCy as compared with price of KCy should bring 24.3 cents per lb.
125. (1) 20.24 per cent. (2) 33.977 grams. (3) 6.8565 liters. (4) 13.713 liters.
126. 32.07.
127. Atomic weight 194.3. Formula RCl_4.
128. (1) 3.16 grams. (2) 0.0056 iron.
129. (1) H_2SO_4 = 34.3 grams. (2) Zinc, 22.75 grams. (3) Hydrogen at 16° and 740 mm. = 8.523 liters.
130. Copper 1.272 grams.
131. 4492 cubic meters.
132. (1) 1760.446 grams. (2) NH_4Cl, 2387.9. KOH (95 per cent.) = 3390.9 grams.
133. Radius of sphere = 5.8872 meters. Volume 854,700 liters. Weight of hydrogen $\frac{1}{11}$ of a metric ton = 76,923 grams. Zinc required = 2495+ kilos. Sulphuric acid = 3742+ kilos.
134. 39 kilograms.
135. $1\frac{1}{2}$ liters.
136. Limestone = 4.434 kilos. Acid = 12.531 kilos.
137. 771 lbs.
138. NaCl = 40 per cent. KCl = 60 per cent.
139. NaCl, 51.96. H_2SO_4, 44.93 lbs.
140. Salt, 3948. Acid, 3809. Water, 7800 (lbs.).
141. Sp. gr. of the solid = 2. Of the liquid = 1.466.
142. 122.408 kilograms.

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143. Zinc = 348.07. Sulphuric acid = 524.79. Potassium chlorate = 218.66. Answers in grams. The two equations have to be written:

$$6Zn + 6H_2SO_4 = 6ZnSO_4 + 6H_2 \text{ and } 2KClO_3 = KCl + 3\ O_2$$

144.

ANALYSIS BY BASES, ETC.		ANALYSIS BY COMPOUNDS.	
Silica	12.06	Silica	12.06
Lime	9.28	Calcium carbonate	10.60
Magnesia	6.41	Magnesium carbonate	13.40
Iron (Fe)	1.46	Ferrous carbonate	3.03
Sodium	15.41	Sodium carbonate	16.22
Radical SO_3	4.77	Calcium sulphate	8.11
Chlorine	12.91	Sodium chloride	21.28
Total parts in 100,000			84.70

145. To one liter of the HCl add 500 c.c. water.
To one liter of the KOH add 266⅔ c.c. water.

146. Weight of limestone 43.779 kilos. Of acid 140.909 kilos. Volume of the gas at zero, 9512 liters. Its weight, 18.685 kilos.

147. $Na_2SnO_3, 4H_2O$.

148. 5.35.

149. 2600 meters.

150. One gram.

151. 62 grams.

152. $H_2S_2O_7$ or $2SO_3 + H_2O$.

153. Each one-tenth of a liter.

154. 20 c.m.

155. 344.42 meters.

156. 9 millimeters.

157. 3 per cent.

158. 100 liters.

159. 736.6, 762, 787.4 millimeters.

160. 30.71, 30.31, 29.92, 29.53, 29.13 inches.

161. $0.16\dot{6}$ or one-sixth.

162. HgC_4H_{10} or $Hg(C_2H_5)_2$.

163. 132.35 cubic centimeters.

164. Atomic weight 52.4.

165. Atomic weight 120.2.

166. $ZnSO_4 = 247.7$. $FeSO_4 = 542.86$. $(NH_4)_2SO_4 = 63.34$ grams.

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167. Chlorine at zero = 83.099 liters. At 20° C. = 89.187 liters. Hydrochloric acid gas exactly double chlorine by the equation. Weight of ortho-phosphoric acid = 145.42 grams.

168. (*a*) P_2H. (*b*) Ag_3AsS_3. (*c*) $KClO_4$. (*d*) Ag_2OFH.

169.

(*a*) Mercury...	71.68 per cent.	(*b*) Gold.....	77.22 per cent.
Hydrogen.	0.36 per cent.	Oxygen....	9.42 per cent.
Nitrogen..	5.02 per cent.	Nitrogen..	11.01 per cent.
Oxygen....	22.94 per cent.	Hydrogen..	2.35 per cent.
	100.00 per cent.		100.00 per cent.
(*c*) Lead.....	77.53 per cent.	(*d*) Tin.....	32.36 per cent.
Carbon....	17.98 per cent.	Chlorine...	57.85 per cent.
Hydrogen.	4.49 per cent.	Nitrogen..	7.62 per cent.
		Hydrogen..	2.17 per cent.
	100.00 per cent.		100.00 per cent.

170. Volume of one gram = 14.2857 c.c.
Gas at 100° occupies 812.7 times volume of liquid, = 11.61 liters.
Minus 238.5° Centigrade.

171. 8.12 lbs.

172. Analysis summed to exact 100 by difference, as below:

Copper (by difference).....	99.956 per cent.
Iron.....	0.016 per cent.
Arsenic.....	0.010 per cent.
Lead.....	0.018 per cent.
	100.000 per cent.

173. 574,165,721,516 metric tons of carbon.
1,071,776,013,496,363 cubic meters of carbon dioxide gas.

174. $CaCO_3$ unacted on = 10 grams.
Weight of solution = 194.66 grams.
Volume of HCl gas 17.92 liters.

175. Tons of coal = 1,500,000,000,000.
Area of coal field = 134,513 square miles nearly.

176. Weight of the P_2O_5 = 171.42 grams
Specific gravity of the nitric acid = 1.52.

177. Weight of hydrogen = 0.02805 gm. Volume = 0.31416 liter.
Weight of sodium = 0.64515 gm. Vol. = 0.6651 cubic cm.
Radius of pellet = 0.5415 cm. Weight of NaOH = 1.122 grams.

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178. 77.07 per cent. MnO_2. 0.167 liters chlorine.

179. 56.81 grams.

180.

ANALYSIS BY "PROXIMATES."		ANALYSIS BY ELEMENTS, ETC.	
SiO_2	36.18 per cent.	SiO_2	36.18 per cent.
FeS_2	12.25 per cent.	Fe	10.27 per cent.
PbS	8.46 per cent.	Pb	7.33 per cent.
ZnS	16.18 per cent.	Zn	10.87 per cent.
Fe_2O_3	6.57 per cent.	S	13.00 per cent.
$CaCO_3$	20.36 per cent.	CaO	11.41 per cent.
		CO_2	8.95 per cent.
		O(with Fe_2O_3)	1.99 per cent.
	100.00 per cent.		100.00 per cent.

181. 2.683 liters.

182. Sp. gr. of heavier liquid = 1.5252.

183. 66.4 per cent.

184. Weight of $BaSO_4$ = 0.0025 gram.

185. 438.8 cubic feet.

186. Atomic weight = 100.

187. MgO = 2.018. NaOH = 4.006. Zn = 3.270. $CaCO_3$ = 5.005.

188. 12, 24, 36 and 48, respectively.

189. Mol. wt. = 104.4.

190. 31.39 per cent. tin.

191. Zinc = 7.521 grams. Hydrogen = 2.670 liters.

192. Per cent. nitrogen = 6.39.

193. Copper weighs 0.8 gram.

194. Vol. of oxygen required = 157.5 c.c.
Vol. of CO_2 produced = 129.8 at 100° C.
Vol. of H_2O produced = 191.3 at 100° C.

195. Analysis by volume:

CO_2	20 per cent.
CO	45 per cent.
H_2	35 per cent.
	100 per cent.

196.

Silver with the chloride	= 0.1855	gram.
Silver with the bromide	= 0.0705	gram.
Silver chloride (AgCl)	= 0.2464	gram.
Silver bromide (AgBr)	= 0.1227	gram.
Chlorine	= 0.0609+	gram.
Bromine	= 0.0522+	gram.

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197. Nitrogen, 6 per cent.
198. Silver bromide = 0.4173. Silver iodide = 0.5217 gram.
199. CO_2 = 210,560 liters; H_2O(1) = 169.2 kilos; (2) = 157.21 kilos.
200. 5.4167 grams.
201. (1) 604.8 cu. m. CO_2 gas. (2) 1244.4432 cu. m. H_2 gas.
202. Specific gravity = 2.689.
203. $KMnO_4$ = 0.5643. $K_2Cr_2O_7$ = 0.8750 gram.
204. Error = $0.0034 or thirty-four hundredths of one cent.
205. 164 millionths of one milligram.
206. 1.281 grams.
207. 9103 millimeters.
208. $KClO_4$.
209. 46.8 approximate molecular weight.
210. 129 approx. mol. wt.
211. 994.68 lbs. MnO_2 of 85 per cent. MnO_2.
Vol. of chlorine, 136.44 cu. ft., normal t and p.
212. 818 mm.
213. CO_2 gas by 0.643 gram.
214. 100 grams.
215. $CaCO_3$ = 446.75 grams. HCl = 200 liters. Weight = 326+ grams.
216. Practically equal.
217. $2HNO_3$, $3H_2O$.
218. 1000 millimeters.
219.

ELEMENTS AND RADICALS.		SALTS.	
CaO	0.05912	$CaSO_4$	0.0322
Cl	1.37549	$CaCO_3$	0.0819
SO_3	0.01894	$MgCl_2$	0.0211
Na	0.89910	Na_2CO_3	0.0416
Mg	0.00533	NaCl	2.2408
CO_2	0.05332		
O(Na_2CO_3)	0.00630		
Total	2.41760	Total	2.4176

These are weights. "Parts per 100,000" may be found by simply dividing by 100.

220. Sphere, 43.9824. Cylinder, 65.9736. Cube, 84.000 grams.
221. Zinc = 6.174. NH_3 = 7.179. H_2SO_4 = 9.308 (grams).

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222. K_2H.
223. 66.66 c.c.
224. 12.12 per cent.
225. Copper, 60; tin, 10; zinc, 30 per cent.
226.

Sulphur...	0.055 per cent.	Phosphorus.	0.059 per cent.
Silicon.....	0.196 per cent.	Manganese.	0.342 per cent.

227. Molecular weight = 34.9.
228. Minus 58° Centigrade.
229. 980.3 c.c. acid, and 19.7 c.c. water.
230. Volume: Nitrogen = 451 liters. Carbon dioxide = 58 liters. Total, 509 liters.
Weight: Nitrogen = 563.7 grams. Carbon dioxide = 113.9 grams. Total, 677.6 grams.
Density $= \frac{(451 \times 28) + (58 \times 44)}{509} = 29.82$.
231. For Fe; 934.56 + 65.44 water. For H_2SO_3; 818.3 + 181.7 water.
For $H_2C_2O_4$; 581.5 + 418.5 water. (Cubic centimeters.)
For Fe; 1 liter + 70 c.c. water. For H_2SO_3; 1 liter + 222 c.c. water.
For $H_2C_2O_4$; 1 liter + 719.7 c.c. water.
232. 85.84 grams.
233. 1.464 per cent. nitrogen.
234. C_6H_6. (Second datum suffices. First gives analysis, not formula.)
235. Radius = 19.929 centimeters.
236. $CO_2 = 1.427$. $H_2O = 0.2413$. $Pt = 1.052$. $AgBr = 1.0159$.
237. R = 1.44 (+) or 1.441 (−) centimeters. Volume = 12.52 c.c. Weight = 21.786 grams.
238. Molecular weight about 126. ($C_{10}H_8$ = 128.)
239. Analysis:

Carbon.....	39.08 per cent.
Hydrogen.....	2.18 per cent.
Nitrogen.....	15.23 per cent.
Oxygen.....	43.51 per cent.
Total.....	100.00 per cent.

Formula: $C_6H_4N_2O_5$.

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240. Oxygen = 1.265 gram = 0.885 liter. Air = 4.215 liters = 0.15 cu. ft.
241. If a dyad, at. wt. = 100. If a triad, at. wt. = 150.
242. Impurities = 5.93 per cent.
243. MnO_2 = 384 grams. Hydrochloric acid solution = 3222 grams. Volume of hydrochloric acid = 2.929 liters.
244. Available chlorine = 44.37 per cent. Will dissolve 820.7 grams gold.
245. 230.003 liters of HCl gas, at 10° and 670 mm.
246. Excess of iron, 0.319 lb. Sulphuric acid used, 1.191 lbs. Deficit of sulphuric acid, 0.559 lb.
247. 124.27 c.c.
248. At. wt. of "M" = 22.32.
249. At. wt. = 100.
250. At. wts. = 24 and 40.
251. Pressure 5709.2 mm., or 7.512 atmospheres. Weight 164.5 kilos.
252. 762.526 liters.
253. Add 0.85 c.c. ammonia solution.
254. HCl solution, 2220.3 c.c. NaOH solution, 3050.1 c.c.
255.

(1) Crude ore contains by assay..... 139 lbs. of lead.
Products contain by assay..... 134.5 lbs. of lead.
Discrepancy (deficit)..... 4.5 lbs. of lead.
(2) Assay of tailings should be 1.26 per cent.

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TABLE I.—ELEMENTS, SYMBOLS AND INTERNATIONAL ATOMIC WEIGHTS, 1912.

Aluminum	Al	27.10	Molybdenum	Mo	96.00
Antimony	Sb	120.20	Neodymium	Nd	144.30
Argon	A	39.88	Neon	Ne	20.20
Arsenic	As	74.96	Nickel	Ni	58.68
Barium	Ba	137.37	Niton	Nt	222.4
Bismuth	Bi	208.00	Nitrogen	N	14.01
Boron	B	11.00	Osmium	Os	190.90
Bromine	Br	79.92	Oxygen	O	16.00
Cadmium	Cd	112.40	Palladium	Pd	106.70
Cæsium	Cs	132.81	Phosphorus	P	31.04
Calcium	Ca	40.07	Platinum	Pt	195.20
Carbon	C	12.00	Potassium	K	39.10
Cerium	Ce	140.25	Praseodymium	Pr	140.60
Chlorine	Cl	35.46	Radium	Ra	226.40
Chromium	Cr	52.00	Rhodium	Rh	102.90
Cobalt	Co	58.97	Rubidium	Rb	85.45
Columbium*	Cb	93.50	Ruthenium	Ru	101.70
Copper	Cu	63.57	Samarium	Sa	150.40
Dysprosium	Dy	162.50	Scandium	Sc	44.10
Erbium	Er	167.70	Selenium	Se	79.20
Europium	Eu	152.00	Silicon	Si	28.30
Fluorine	F	19.00	Silver	Ag	107.88
Gadolinium	Gd	157.30	Sodium	Na	23.00
Gallium	Ga	69.90	Strontium	Sr	87.63
Germanium	Ge	72.50	Sulphur	S	32.07
Glucinum†	Gl	9.10	Tantalum	Ta	181.50
Gold	Au	197.20	Tellurium	Te	127.50
Helium	He	3.99	Terbium	Tb	159.20
Hydrogen	H	1.008	Thallium	Tl	204.00
Indium	In	114.80	Thorium	Th	232.40
Iodine	I	126.92	Thulium	Tm	168.50
Iridium	Ir	193.10	Tin	Sn	119.00
Iron	Fe	55.84	Titanium	Ti	48.10
Krypton	Kr	82.92	Tungsten	W	184.00
Lanthanum	La	139.00	Uranium	U	238.50
Lead	Pb	207.10	Vanadium	V	51.00
Lithium	Li	6.94	Xenon	Xe	130.20
Lutecium‡	Lu	174.00	Ytterbium§	Yb	172.00
Magnesium	Mg	24.32	Yttrium	Y	89.00
Manganese	Mn	54.93	Zinc	Zn	65.37
Mercury	Hg	200.60	Zirconium	Zr	90.60

*Columbium, formerly Niobium. †Glucinum, formerly Beryllium.

‡Lutecium, recently separated from Ytterbium.

§Ytterbium, for which Urbain gives the name Neo-ytterbium. It is better to retain the old name.

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Actinium and polonium are also recognized as elements, but no atomic weights have as yet been determined for them.

O = 16 is now the accepted basis of comparison. If at. wt. of an element be desired on basis of H = 1, use factor 0.9925.

Example.—Carbon = 12.

12 × 0.9925 = 11.91, which was at. wt. of C when H = 1.

Tabulation of old numbers is omitted, to lessen danger of error in "taking out" from wrong table.

TABLE II.—CHEMICAL FACTORS AND THEIR LOGARITHMS.

	Known.	Required.	Factor.	Logarithm.
Aluminum.....	Al_2O_3	Al	0.5303	9.7245
	$AlPO_4$	Al_2O_3	0.4185	9.6217
	Al_2O_3	$KAl(SO_4)_2 + 12H_2O$	9.2869	0.9678
Antimony.....	Sb_2S_3	Sb	0.7142	9.8538
	Sb_2O_4	Sb	0.7897	9.8975
Arsenic.....	$Mg_2As_2O_7$	As	0.4827	9.6837
	$Mg_2As_2O_7$	As_2O_3	0.6373	9.8043
	$Mg_2As_2O_7$	As_2O_5	0.7403	9.8694
	As_2S_2	As	0.6091	9.7847
	As_2S_3	As_2O_3	0.8041	9.9053
	As_2S_5	As_2O_5	0.9341	9.9704
	Ag (from Ag_3AsO_4)	As	0.2316	9.3647
	AgCl (from Ag_3AsO_4)	As	0.1743	9.2413
Barium.....	$BaSO_4$	Ba	0.5885	9.7698
	$BaSO_4$	BaO	0.6570	9.8176
	$BaCO_3$	Ba	0.6960	9.8426
	$BaCO_3$	BaO	0.7771	9.8905
	$BaCrO_4$	Ba	0.5420	9.7340
	$BaCrO_4$	BaO	0.6051	9.7819
Bismuth.....	Bi_2O_3	Bi	0.8966	9.9526
	BiOCl	Bi	0.8017	9.9040
	BiOCl	Bi_2O_3	0.8942	9.9514
Boron.....	B_2O_3	B	0.3143	9.4973
Bromine.....	AgBr	Br	0.4256	9.6290
	AgBr	HBr	0.4309	9.6344
	HBr	Br	0.9875	9.9945
	KBr	Br	0.6715	9.8270
Cadmium.....	CdO	Cd	0.8754	9.9422
Calcium.....	CaO	Ca	0.7146	9.8541
	CaO	$CaCO_3$	1.7847	0.2516
	$CaSO_4$	Ca	0.2943	9.4688
	$CaSO_4$	CaO	0.4119	9.6148

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TABLE II.—CHEMICAL FACTORS AND THEIR LOGARITHMS—*Continued.*

	Known.	Required.	Factor.	Logarithms.
Calcium, *continued*..	$CaCO_3$	Ca	0.4004	9.6025
	$CaCO_3$	CaO	0.5603	9.7484
Carbon.....	CO_2	C	0.2727	9.4357
	C	CO_2	3.6667	0.5643
Chlorine.....	AgCl	Cl	0.2474	9.3934
	AgCl	HCl	0.2544	9.4055
	Ag	Cl	0.3287	9.5168
	Ag	HCl	0.3380	9.5289
	HCl	Cl	0.9724	9.9879
Chromium.....	Cr_2O_3	Cr	0.6842	9.8352
	Cr_2O_3	CrO_3	1.3158	0.1192
	$PbCrO_4$	Cr	0.1609	9.2066
	$PbCrO_4$	CrO_3	0.3095	9.4907
	$BaCrO_4$	Cr	0.2052	9.3122
	$BaCrO_4$	CrO_3	0.3947	9.5963
Cobalt.....	$CoSO_4$	Co	0.3803	9.5801
	$CoSO_4$	CoO	0.4835	9.6844
	Co	CoO	1.2713	0.1042
Copper.....	Cu	CuO	1.2517	0.0975
	Cu	Cu_2S	1.2522	0.0977
	CuO	Cu	0.7989	9.9025
	Cu_2S	Cu	0.7986	9.9023
	Cu_2S	CuO	0.9996	9.9998
	$CuSO_4$	Cu	0.3982	9.6001
Fluorine.....	CaF_2	F	0.4866	9.6871
	CaF_2	HF	0.5124	9.7096
Gold.....	Au	$AuCl_3$	1.5394	0.1873
Hydrogen.....	H_2O	H	0.1119	9.0487
	HCl	H	0.0276	8.4409
Iodine.....	AgI	I	0.5405	9.7328
	AgI	HI	0.5448	9.7362
Iron.....	Fe	FeO	1.2865	0.1094
	Fe	Fe_2O_3	1.4298	0.1553
	Fe	Fe_3O_4	1.3820	0.1405
	Fe	FeS_2	2.1486	0.3322
	FeO	Fe	0.7773	9.8906
	FeO	Fe_2O_3	1.1114	0.0459
	Fe_2O_3	Fe	0.6994	9.8447
	Fe_2O_3	FeO	0.8998	9.9541
	Fe_2O_3	Fe_3O_4	0.9666	9.9853
	Fe_2O_3	FeS_2	1.5028	0.1769
	Fe_3O_4	Fe	0.7236	9.8595
	FeS_2	Fe	0.4654	9.6678
	FeS_2	FeO	0.5988	9.7773

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TABLE II.—CHEMICAL FACTORS AND THEIR LOGARITHMS—*Continued.*

	Known.	Required.	Factor.	Logarithms.
Iron, *continued*.....	FeS_2	Fe_2O_3	0.6654	9.8231
	S	FeS_2	1.8706	0.2720
Lead.....	PbO	Pb	0.9283	9.9677
	PbS	Pb	0.8659	9.9375
	PbS	PbO	0.9328	9.9698
	$PbSO_4$	Pb	0.6831	9.8345
	$PbSO_4$	PbO	0.7359	9.8668
	$PbSO_4$	PbS	0.7888	9.8969
	$PbSO_4$	$PbCO_3$	0.8810	9.9450
	$PbCrO_4$	Pb	0.6408	9.8067
	$PbCrO_4$	PbO	0.6903	9.8390
Lithium.....	LiCl	Li	0.1637	9.2140
	LiCl	Li_2O	0.3524	9.5470
Magnesium.....	$Mg_2P_2O_7$	Mg	0.2184	9.3393
	$Mg_2P_2O_7$	MgO	0.3621	9.5588
	$Mg_2P_2O_7$	$MgCO_3$	0.7572	9.8792
	$Mg_2P_2O_7$	$MgCl_2$	0.8552	9.9321
	$MgCO_3$	MgO	0.4782	9.6796
	MgO	Mg	0.6032	9.7805
Manganese.....	$Mn_2P_2O_7$	Mn	0.3870	9.5877
	$Mn_2P_2O_7$	MnO	0.4998	9.6988
	Mn_3O_4	Mn	0.7203	9.8575
	Mn_3O_4	MnO	0.9301	9.9685
	MnS	Mn	0.6313	9.8002
	MnS	MnO	0.8153	9.9113
Mercury.....	Hg	HgO	1.0798	0.0333
	HgS	Hg	0.8622	9.9356
	HgS	HgO	0.9309	9.9689
	HgCl	Hg	0.8498	9.9293
	HgCl	HgO	0.9176	9.9627
Molybdenum.....	MoO_3	Mo	0.6667	9.8240
	MoO_3	MoS_2	1.1119	0.0460
Nickel.....	NiO	Ni	0.7858	9.8953
	$NiSO_4$	Ni	0.3792	9.5789
	$NiSO_4$	NiO	0.4826	9.6836
Nitrogen.....	Pt	N	0.1435	9.1569
	Pt	NH_3	0.1745	9.2418
	Pt	NH_4	0.1849	9.2669
	$(NH_4)_2PtCl_6$	N	0.0631	8.8000
	$(NH_4)_2PtCl_6$	NH_3	0.0767	8.8848
	$(NH_4)_2PtCl_6$	NH_4	0.0813	8.9101
	N	NH_3	1.2158	0.0848
	N	N_2O_5	3.8551	0.5861
Oxygen.....	H_2O	O	0.8881	9.9484

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TABLE II.—CHEMICAL FACTORS AND THEIR LOGARITHMS—*Continued.*

	Known.	Required.	Factor.	Logarithms.
Phosphorus.....	$Mg_2P_2O_7$	P	0.2787	9.4451
	$Mg_2P_2O_7$	PO_4	0.8534	9.9312
	$Mg_2P_2O_7$	P_2O_5	0.6379	9.8048
	$(UO_2)_2P_2O_7$	P_2O_5	0.1987	9.2982
Platinum.....	Pt	$PtCl_4$	1.7266	0.2372
	$PtCl_4$	Pt	0.5791	9.7628
Potassium.....	KCl	K	0.5244	9.7197
	KCl	K_2O	0.6317	9.8005
	K_2PtCl_6	K	0.1609	9.2066
	K_2PtCl_6	K_2O	0.1938	9.2874
	K_2PtCl_6	KCl	0.3069	9.4870
	Pt	K	0.4006	9.6027
	Pt	K_2O	0.4826	9.6836
Selenium.....	Se	SeO_2	1.4040	0.1473
Silicon.....	SiO_2	Si	0.4693	9.6715
	Si	SiO_2	2.1308	0.3285
Silver.....	AgCl	Ag	0.7526	9.8766
	AgBr	Ag	0.5744	9.7592
	AgI	Ag	0.4595	9.6623
	Ag_2S	Ag	0.8706	9.9398
Sodium.....	NaCl	Na	0.3934	9.5948
	NaCl	Na_2O	0.5303	9.7245
	Na_2CO_3	Na_2O	0.5849	9.7671
	Na_2SO_4	Na_2O	0.4364	9.6399
Strontium.....	$SrSO_4$	Sr	0.4770	9.6785
	$SrSO_4$	SrO	0.5641	9.7514
Sulphur.....	$BaSO_4$	S	0.1374	9.1380
	$BaSO_4$	SO_3	0.3430	9.5353
	$BaSO_4$	H_2SO_4	0.4202	9.6235
	$BaSO_4$	SO_4	0.4115	9.6143
Tin.....	SnO_2	Sn	0.7881	9.8966
Titanium.....	TiO_2	Ti	0.6005	9.7786
Tungsten.....	WO_3	W	0.7931	9.8994
Uranium.....	$(UO_2)_2P_2O_7$	U	0.6671	9.8242
	$(UO_2)_2P_2O_7$	U_3O_8	0.7865	9.8957
	U_3O_8	U	0.8483	9.9286
Vanadium.....	V_2O_5	V	0.5604	9.7485
Zinc.....	ZnO	Zn	0.8034	9.9049
	ZnO	ZnS	1.1975	0.0783
	ZnS	Zn	0.6709	9.8267
	ZnS	ZnO	0.8351	9.9217

The above table of factors is calculated from the atomic weights as given by the "International" committee of 1912.

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TABLE III.—NAMES, SYMBOLS, MOLAR WEIGHTS AND PERCENTAGE COMPOSITION OF THE MORE IMPORTANT INORGANIC COMPOUNDS, CHEMICALLY CLASSIFIED.

Names.	Formulæ.	Molar Wts.	Percentage Composition.
ANHYDRIDES.			
Arsenic	As_2O_5	229.92	As, 65.21 . O, 34.79
Arsenious	As_2O_3	197.92	As, 75.75 . O, 24.25
Antimonic	Sb_2O_5	320.40	Sb, 75.03 . O, 24.97
Boric	B_2O_3	70.00	B, 31.43 . O, 68.57
Carbonic	CO_2	44.00	C, 27.27 . O, 72.73
Chromic	CrO_3	100.00	Cr, 52.00 . O, 48.00
Molybdic	MoO_3	144.00	Mo, 66.67 . O, 33.33
Nitric	N_2O_5	108.02	N, 25.94 . O, 74.06
Nitrous	N_2O_3	76.02	N, 36.86 . O, 63.14
Permanganic	Mn_2O_7	221.86	Mn, 49.52 . O, 50.48
Phosphoric	P_2O_5	142.08	P, 43.69 . O, 56.31
Phosphorous	P_2O_3	110.08	P, 56.39 . O, 43.61
Silicic	SiO_2	60.30	Si, 46.93 . O, 53.07
Sulphuric	SO_3	80.07	S, 40.05 . O, 59.95
Sulphurous	SO_2	64.07	S, 50.05 . O, 49.95
Titanic	TiO_2	80.10	Ti, 60.05 . O, 39.95
Tungstic	WO_3	232.00	W, 79.31 . O, 20.69
Vanadic	V_2O_5	182.00	V, 56.04 . O, 43.96
ARSENIATES.			
Hydrogen	H_3AsO_4	141.984	As_2O_5, 80.97 . H_2O, 19.03
Am.-Magnesium	$(NH_4MgAsO_4)_2H_2O$	380.65	NH_3, 8.95 . MgO, 21.19 . As_2O_5, 60.40 . H_2O, 9.46
Mg. (pyro.)	$Mg_2As_2O_7$	310.56	MgO, 25.97 . As_2O_5, 74.03 (As = 48.27)
Silver	Ag_3AsO_4	462.60	Ag, 69.96 . As, 16.20 . (O_4 = 13.84)
ARSENITES.			
Hydrogen	H_3AsO_3	125.984	As_2O_3, 78.55 . H_2O, 21.45
Mg. (tertiary)	$Mg_3(AsO_3)_2$	318.88	As_2O_3, 62.07 . MgO, 37.93
Ag. (tertiary)	Ag_3AsO_3	446.60	Ag, 72.47 . As, 16.78. O_3 = 10.75
BORATES.			
Hydrogen	$B(OH)_3$	62.024	H_2O, 43.57 . B_2O_3, 56.43
Borax (glass)	$Na_2B_4O_7$	202.00	Na_2O, 30.69 . $(B_2O_3)_2$, 69.31
Borax (cryst.)	$Na_2B_4O_7 + 5Aq.$	292.08	H_2O, 30.87 . $Na_2B_4O_7$, 69.13
BROMIDES.			
Hydrogen	HBr	80.928	H, 1.25 . Br, 98.75
Potassium	KBr	119.02	K, 32.85 . Br, 67.15

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
Silver.....	AgBr	187.80	Ag, 57.44 . Br, 42.56
Sodium.....	NaBr	102.92	Na, 22.35 . Br, 77.65
CARBONATES.			
Hydrogen.....	H_2CO_3	62.016	H_2O, 29.05 . CO_2, 70.95
Ammonium.....	$(NH_4)_2CO_3$	96.084	NH_3, 35.46 . H_2O, 18.75 . CO_2, 45.79
Am. (primary)...	NH_4HCO_3	79.05	NH_3, 21.55 . H_2O, 22.79 . CO_2, 55.66
Barium.....	$BaCO_3$	197.37	BaO, 77.71 . CO_2, 22.29
Calcium.....	$CaCO_3$	100.07	CaO, 56.03 . CO_2, 43.97
Ferrous.....	$FeCO_3$	115.85	FeO, 62.02 . CO_2, 37.98 (Fe = 48.20)
Lead.....	$PbCO_3$	267.1	PbO, 83.53 . CO_2, 16.47 (Pb = 77.54)
Lithium.....	Li_2CO_3	73.88	Li_2O, 40.44 . CO_2, 59.56
Magnesium.....	$MgCO_3$	84.32	MgO, 47.82 . CO_2, 52.18
Manganese.....	$MnCO_3$	114.93	MnO, 61.72 . CO_2, 38.28
Potassium.....	K_2CO_3	138.2	K_2O, 68.16 . CO_2, 31.84
Potassium (prim.)	$KHCO_3$	100.108	K_2O, 47.05 . H_2O, 9.00. CO_2, 43.95
Sodium.....	Na_2CO_3	106.0	Na_2O, 58.49 . CO_2, 41.51
Sodium (primary)	$NaHCO_3$	84.008	Na_2O, 36.90.. H_2O, 10.72 . CO_2, 52.38
Sodium (cryst) ..	$Na_2CO_3 + 10Aq.$	286.16	Na_2CO_3, 37.04 . H_2O, 62.96 . (Na_2O, 21.67)
Strontium.....	$SrCO_3$	147.63	SrO, 70.20 . CO_2, 29.80
Zinc.....	$ZnCO_3$	125.37	ZnO, 64.90 . CO_2, 35.10
CHLORATES.			
Hydrogen.....	$HClO_3$	84.468	H, 1.19 . Cl, 41.98 . O, 56.83
Potassium.....	$KClO_3$	122.56	K, 31.90 . Cl, 28.93 . O, 39.17
Sodium.....	$NaClO_3$	106.46	Na, 21.60 . Cl, 33.30 . O, 45.10
Strontium.....	$Sr(ClO_3)_2$	254.55	Sr, 34.42 . Cl, 27.86 . O, 37.72
CHLORIDES.			
Hydrogen.....	HCl	36.468	H, 2.76 . Cl, 97.24
Aluminum.....	$AlCl_3$	133.48	Al, 20.30 . Cl, 79.70
Ammonium.....	NH_4Cl	53.502	NH_4, 33.72 . Cl, 66.28 (NH_3, 31.84)

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
Antimonious....	$SbCl_3$	226.58	Sb, 53.05 . Cl, 46.95
Arsenious.....	$AsCl_3$	181.34	As, 41.34 . Cl, 58.66
Barium.....	$BaCl_2$	208.29	Ba, 65.95 . Cl, 34.05
Barium (cryst.) .	$BaCl_2 + 2H_2O$	244.322	$BaCl_2$, 85.25 . H_2O, 14.75
Bismuth.....	$BiCl_3$	314.38	Bi, 66.17 . Cl, 33.83
Cadmium.....	$CdCl_2$	183.32	Cd, 61.32 . Cl, 38.68
Calcium.....	$CaCl_2$	110.99	Ca, 36.10 . Cl, 63.90
Cuprous.....	$CuCl$	99.03	Cu, 64.19 . Cl, 35.81
Cupric.....	$CuCl_2$	134.49	Cu, 47.27 . Cl, 52.73
Ferric.....	$FeCl_3$	162.22	Fe, 34.42 . Cl, 65.58
Ferrous.....	$FeCl_2$	126.76	Fe, 44.05 . Cl, 55.95
Gold.....	$AuCl_3$	303.58	Au, 64.96 . Cl, 35.04
Iodine.....	ICl_3	233.30	I, 54.40 . Cl, 45.60
Lead.....	$PbCl_2$	278.02	Pb, 74.49 . Cl, 25.51
Lithium.....	$LiCl$	42.40	Li, 16.37 . Cl, 83.63
Magnesium.....	$MgCl_2$	95.24	Mg, 25.54 . Cl, 74.46
Manganous.....	$MnCl_2$	125.85	Mn, 43.65 . Cl, 56.35
Mercuric.....	$HgCl_2$	271.52	Hg, 73.88 . Cl, 26.12
Mercurous.....	$HgCl$	236.06	Hg, 84.98 . Cl, 15.02
Nickel.....	$NiCl_2$	129.60	Ni, 45.28 . Cl, 54.72
Phosphoric.....	PCl_5	208.34	P, 14.90 . Cl, 85.10
Phosphorous.....	PCl_3	137.42	P, 22.59 . Cl, 77.41
P-oxychloride....	$POCl_3$	153.42	P, 20.23 . O, 10.43 . Cl, 69.34
Platinum.....	$PtCl_4$	337.04	Pt, 57.92 . Cl, 42.08
Pt. Ammonium..	$(NH_4)_2PtCl_6$	444.044	N, 6.31 . Pt, 43.96 . Cl, 47.91 . H, 1.82
Pt. Potassium...	K_2PtCl_6	486.16	K, 16.09 . Pt, 40.15 . Cl, 43.76
Potassium.....	KCl	74.56	K, 52.44 . Cl, 47.56
Silicon.....	$SiCl_4$	170.14	Si, 16.63 . Cl, 83.37
Silver.....	$AgCl$	143.34	Ag, 75.26 . Cl, 24.74
Sodium.....	$NaCl$	58.46	Na, 39.34 . Cl, 60.66
Strontium.....	$SrCl_2$	158.55	Sr, 55.27 . Cl, 44.73
Sulphur.....	S_2Cl_2	135.06	S, 47.49 . Cl, 52.51
Tin.....	$SnCl_4$	260.84	Sn, 45.62 . Cl, 54.38
Titanium.....	$TiCl_4$	189.94	Ti, 25.32 . Cl, 74.68
Zinc.....	$ZnCl_2$	136.29	Zn, 47.96 . Cl, 52.04
CHROMATES.			
Hydrogen.....	H_2CrO_4	118.016	H_2O, 15.27 . CrO_3, 84.73
Barium.....	$BaCrO_4$	253.37	BaO, 60.53 . CrO_3, 39.47
Lead.....	$PbCrO_4$	323.10	PbO, 69.05 . CrO_3, 30.95

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
Potassium.....	K_2CrO_4	194.20	K_2O, 48.51 . CrO_3, 51.49
K. (bichromate).	$K_2Cr_2O_7$	294.20	K_2O, 32.02 . CrO_3, 67.98
Silver.....	Ag_2CrO_4	331.76	Ag_2O, 69.86 . CrO_3, 30.14
Sodium.....	Na_2CrO_4	162.00	Na_2O, 38.27 . CrO_3, 61.73
CYANIDES.			
Hydrogen.....	HCN	27.018	H, 3.73 . C, 44.41 . N, 51.85. (CN = 96.26)
Potassium.....	KCN	65.11	K, 60.05 . C, 18.43 . N, 21.52. (CN = 39.95)
Sodium.....	NaCN	49.01	Na, 46.93 . C, 24.48 . N, 28.59. (CN = 53.07)
Ferric ferroCy...	$Fe_4(FeCy_6)_3$	859.06	Fe, 45.50 . CN, 54.50
K ferricyanide...	$K_3Fe(CN)_6$	329.20	K, 35.63 . Fe, 16.96 . CN, 47.41
K ferrocyanide..	$K_4FeCy_6 + 3H_2O$	422.348	K, 37.03 . Fe, 13.22 . CN, 36.95 . H_2O, 12.80
K sulphocyanide.	KCNS	97.18	K, 40.23 . CNS, 59.77 (CN, 26.77 . S, 33.00)
Cyanogen.....	C_2N_2	52.02	C, 46.14 . N, 53.86
FLUORIDES.			
Hydrogen.....	HF	20.008	H, 5.04 . F, 94.96
Boron.....	BF_3	68.00	B, 16.18 . F, 83.82
Calcium.....	CaF_2	78.07	Ca, 51.33 . F, 48.67
Silicon.....	SiF_4	104.3	Si, 27.13 . F, 72.87
HYDRIDES.			
Ammonia.....	NH_3	17.034	N, 82.25 . H, 17.75
Arsine.....	AsH_3	78.024	As, 96.12 . H, 3.88
Boron hydride...	BH_3	14.984	B, 78.44 . H, 21.56
Phosphine.....	PH_3	34.064	P, 91.12 . H, 8.88
Stibine.....	SbH_3	123.224	Sb, 97.55 . H, 2.45
Silicon.....	SiH_4	32.332	Si, 87.53 . H, 12.47
HYDROCARBONS.			
Methane.....	CH_4	16.032	C, 74.84 . H, 25.16
Acetylene.....	C_2H_2	26.016	C, 92.25 . H, 7.75
Ethylene.....	C_2H_4	28.032	C, 85.62 . H, 14.38
Ethane.....	C_2H_6	30.048	C, 79.87 . H, 20.13
Propane.....	C_3H_8	44.064	C, 81.70 . H, 18.30
Butane.....	C_4H_{10}	58.08	C, 82.64 . H, 17.36
Benzol.....	C_6H_6	78.048	C, 92.25 . H, 7.75

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
HYDROXIDES.			
Aluminum.....	$Al(OH)_3$	78.124	Al_2O_3, 65.41 . H_2O, 34.59
Ammonium.....	NH_4OH	35.05	NH_3, 48.60 . H_2O, 51.40
Barium.....	$Ba(OH)_2$	171.386	BaO, 89.49 . H_2O, 10.51
Bismuth.....	$Bi(OH)_3$	259.024	Bi_2O_3, 89.57 . H_2O, 10.43
Calcium.....	$Ca(OH)_2$	74.086	CaO, 75.68 . H_2O, 24.32
Ferric.....	$Fe(OH)_3$	106.864	Fe_2O_3, 74.71 . H_2O, 25.29
Lead.....	$Pb(OH)_2$	241.116	PbO, 92.52 . H_2O, 7.48
Potassium.....	KOH	56.108	K_2O, 83.94 . H_2O, 16.06
Sodium.....	NaOH	40.008	Na_2O, 77.48 . H_2O, 22.52
Zinc.....	$Zn(OH)_2$	99.386	ZnO, 81.87 . H_2O, 18.13
IODIDES.			
Hydrogen.....	HI	127.928	H, 0.79 . I, 99.21
Lithium.....	LiI	133.86	Li, 5.18 . I, 94.82
Potassium.....	KI	166.02	K, 23.55 . I, 76.45
Silver.....	AgI	234.80	Ag, 45.95 . I, 54.05
MOLYBDATES.			
Hydrogen.....	H_2MoO_4	162.016	H_2O, 11.12 . MoO_3, 88.88
Ammonium.....	$(NH_4)_2MoO_4$	196.084	$(NH_4)_2O$, 26.56 . MoO_3, 73.44
Lead.....	$PbMoO_4$	367.10	PbO, 60.77 . MoO_3, 39.23 (Pb = 56.42)
NITRATES.			
Hydrogen.....	HNO_3	63.018	H_2O, 14.29 . N_2O_5, 85.71 . H, 1.60 . N, 22.23 . O, 76.17
Ammonium.....	NH_4NO_3	80.052	H_2O, 11.25 . NH_3, 21.28 . N_2O_5, 67.47
Barium.....	$Ba(NO_3)_2$	261.39	BaO, 58.68 . N_2O_5, 41.32
Bismuth.....	$Bi(NO_3)_3$	394.03	Bi_2O_3, 58.88 . N_2O_5, 41.12
Bismuth (cryst.).	$Bi(NO_3)_3 + 5Aq.$	484.110	$Bi(NO_3)_3$, 81.39 . H_2O, 18.61
Calcium.....	$Ca(NO_3)_2$	164.09	CaO, 34.17 . N_2O_5, 65.83
Copper.....	$Cu(NO_3)_2 + 3Aq.$	241.638	CuO, 32.93 . N_2O_5, 44.70 H_2O, 22.37
Lead.....	$Pb(NO_3)_2$	331.12	PbO, 67.38 . N_2O_5, 32.62
Lead (basic).....	$Pb(NO_3)(OH)$	286.118	PbO, 77.97 . N_2O_5, 18.87 . H_2O, 3.16
Mercuric.....	$Hg(NO_3)_2$	324.62	HgO, 66.72 . N_2O_5, 33.28
Mercurous.....	$HgNO_3$	262.61	Hg_2O, 79.43 . N_2O_5, 20.57
Potassium.....	KNO_3	101.11	K_2O, 46.58 . N_2O_5, 53.42
Silver.....	$AgNO_3$	169.89	Ag_2O, 68.21 . N_2O_5, 31.79

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
Sodium.....	$NaNO_3$	85.01	Na_2O, 36.47 . N_2O_5, 63.53
Strontium.....	$Sr(NO_3)_2$	211.65	SrO, 48.96 . N_2O_5, 51.04
NITRITES.			
Hydrogen.....	HNO_2	47.018	H_2O, 19.16 . N_2O_3, 80.84
Ammonium.....	NH_4NO_2	64.052	$(NH_4)_2O$, 40.66 . N_2O_3, 59.34 . $\begin{cases} N_2 = 43.75 \\ 2H_2O = 56.25 \end{cases}$
Potassium.....	KNO_2	85.11	K_2O, 55.34 . N_2O_3, 44.66
Silver.....	$AgNO_2$	153.89	Ag_2O, 75.30 . N_2O_3, 24.70 (Ag = 70.10)
Sodium.....	$NaNO_2$	69.01	Na_2O, 44.92 . N_2O_3, 55.08
OXIDES.			
Hydrogen.....	H_2O	18.016	H, 11.19 . O, 88.81
Hydrogen (per)..	H_2O_2	34.016	H, 5.93 . O, 94.07
Aluminum.....	Al_2O_3	102.2	Al, 53.03 . O, 46.97
Antimony.....	Sb_2O_3	288.4	Sb, 83.35 . O, 16.65
Barium.....	BaO	153.37	Ba, 89.57 . O, 10.43
Barium (per)....	BaO_2	169.37	Ba, 81.11 . O, 18.89
Bismuth.....	Bi_2O_3	464.0	Bi, 89.66 . O, 10.34
Cadmium.....	CdO	128.4	Cd, 87.54 . O, 12.46
Calcium.....	CaO	56.07	Ca, 71.46 . O, 28.54
Carbon.....	CO	28.0	C, 42.86 . O, 57.14
Carbon (di-).....	CO_2	44.0	C, 27.27 . O, 72.73
Chromium.....	Cr_2O_3	152.0	Cr, 68.42 . O, 31.58
Cobaltic.....	Co_2O_3	165.94	Co, 71.07 . O, 28.93
Cobaltous.....	CoO	74.97	Co, 78.66 . O, 21.34
Cupric.....	CuO	79.57	Cu, 79.89 . O, 20.11
Cuprous.....	Cu_2O	143.14	Cu, 88.82 . O, 11.18
Ferric.....	Fe_2O_3	159.68	Fe, 69.94 . O, 30.06
Ferro-ferric.....	Fe_3O_4	231.52	Fe, 72.36 . O, 27.64
Ferrous.....	FeO	71.84	Fe, 77.73 . O, 22.27
Lead.....	PbO	223.1	Pb, 92.83 . O, 7.17
Lead (per).....	PbO_2	239.1	Pb, 86.62 . O, 13.38
Magnesium.....	MgO	40.32	Mg, 60.32 . O, 39.68
Manganic.....	Mn_2O_3	157.86	Mn, 69.59 . O, 30.41
Manganous.....	MnO	70.93	Mn, 77.44 . O, 22.56
Manganese (per).	MnO_2	86.93	Mn, 63.19 . O, 36.81
Mercuric.....	HgO	216.60	Hg, 92.61 . O, 7.39
Mercurous.....	Hg_2O	417.2	Hg, 96.16 . O, 3.84
Nickel.....	NiO	74.68	Ni, 78.58 . O, 21.42
Nitric.....	NO	30.01	N, 46.70 . O, 53.30

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
Nitrous.....	N_2O	44.02	N, 63.65 . O, 36.35
Potassium.....	K_2O	94.2	K, 83.01 . O, 16.99
Sodium.....	Na_2O	62.00	Na, 74.19 . O, 25.81
Strontium	SrO	103.63	Sr, 84.56 . O, 15.44
Tin.....	SnO_2	151.0	Sn, 78.81 . O, 21.19
Uranic.....	UO_3	286.5	U, 83.25 . O, 16.75
Uranous.....	UO_2	270.5	U, 88.17 . O, 11.83
Uran. ous-ic.....	U_3O_8	843.5	U, 84.83 . O, 15.17
Zinc.....	ZnO	81.37	Zn, 80.34 . O, 19.66
PHOSPHATES.			
Hydrogen Meta .	HPO_3	80.048	H_2O, 11.24 . P_2O_5, 88.75
Hydrogen Pyro..	$H_4P_2O_7$	178.112	H_2O, 20.23 . P_2O_5, 79.77
Hydrogen Ortho.	H_3PO_4	98.064	H_2O, 27.56 . P_2O_5, 72.44
Aluminum.....	$AlPO_4$	122.14	Al_2O_3, 41.84 . P_2O_5, 58.16
Ammonium.....	$NH_4H_2PO_4$	115.098	$(NH_4)_2O$, 22.62 . H_2O, 15.66 . P_2O_5, 61.72
Microcosmic salt.	NH_4NaHPO_4+4Aq	209.154	$(NH_4)_2O$, 12.45 . H_2O, 4.31 . Na_2O, 14.82 . P_2O_5, 33.96 . (H_2O, cryst. 34.46)
Am. Magnesium.	$NH_4MgPO_4+6H_2O$	245.498	$(NH_4)_2O$, 10.61 . MgO, 16.42 . P_2O_5, 28.94 . H_2O of cryst. 44.03
Am. Manganese.	NH_4MnPO_4	168.012	$(NH_4)_2O$, 15.50 . MnO, 42.22 . P_2O_5, 42.28
Calcium (prim)..	$CaH_4(PO_4)_2$	234.182	CaO, 23.94 . H_2O, 15.39 . P_2O_5, 60.67
Calcium (2nd)...	$CaHPO_4$	136.118	CaO, 41.19 . H_2O, 6.62 . P_2O_5, 52.19
Calcium (3rd)...	$Ca_3(PO_4)_2$	310.29	CaO, 54.21 . P_2O_5, 45.79
Ferric.....	$FePO_4$	150.88	Fe_2O_3, 52.91 . P_2O_5, 47.09
Lithium.....	Li_3PO_4	115.86	Li_2O, 38.68 . P_2O_5, 61.32
Magnesium pyro.	$Mg_2P_2O_7$	222.72	MgO, 36.21 (P=27.87) P_2O_5, 63.79
Manganese pyro.	$Mn_2P_2O_7$	283.94	MnO, 49.96 P_2O_5, 50.04
Potassium, 1st ..	KH_2PO_4	136.156	K_2O, 34.58 . H_2O, 13.24 P_2O_5, 52.18
Potassium, 2nd ..	K_2HPO_4	174.248	K_2O, 54.06 . H_2O, 5.17 . P_2O_5, 40.77
Potassium, 3rd ..	K_3PO_4	212.34	K_2O, 66.55 . P_2O_5, 33.45
Silver.....	Ag_3PO_4	418.68	Ag_2O, 83.03 . (Ag, 77.30) P_2O_5, 16.97

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
Sodium.....	NaH_2PO_4	120.046	Na_2O, 25.82 . H_2O, 15.01 P_2O_5, 59.17
Sodium, 2nd	Na_2HPO_4	142.048	Na_2O, 43.65 . H_2O, 6.34 . P_2O_5, 50.01
Sodium, 3rd	Na_3PO_4	164.04	Na_2O, 56.69 . P_2O_5, 43.31
Na., 2nd, cryst...	Na_2HPO_4+12Aq	358.24	Na_2O, 17.31 . H_2O, 2.51 . P_2O_5, 19.83. Water of crystallization, 60.35
SULPHATES.			
Hydrogen.....	H_2SO_4	98.086	H_2O, 18.37 . SO_3, 81.63
Hydrogen pyro..	$H_2S_2O_7$	178.156	H_2O, 10.11 . SO_3, 89.89
Aluminum.....	$Al_2(SO_4)_3$	342.41	Al_2O_3, 29.85 . SO_3, 70.15
Aluminum cryst..	$Al_2(SO_4)_3+18Aq$	666.698	Al_2O_3, 15.33 . SO_3, 36.03 . H_2O, 48.64
Ammonium.....	$(NH_4)_2SO_4$	132.154	$(NH_4)_2O$, 39.41 SO_3, 60.59
Ammonium alum	$NH_4Al(SO_4)_2+12Aq$	453.474	$(NH_4)_2O$, 5.74 . Al_2O_3, 11.27 . SO_3, 35.31 . Water cryst. 47.68
Am-ferrous.....	$Fe(NH_4)_2(SO_4)_2+6Aq$	392.16	$(NH_4)_2O$, 13.28 . FeO, 18.32 . SO_3, 40.84 . Water cryst. 27.56
Barium.....	$BaSO_4$	233.44	BaO, 65.70 . SO_3, 34.30
Cadmium.....	$CdSO_4$	208.47	CdO, 61.69 . SO_3, 38.31
Calcium.....	$CaSO_4$	136.14	CaO, 41.18 . SO_3, 58.82
Calcium, gypsum.	$CaSO_4+2H_2O$	172.172	CaO, 32.57 . SO_3, 46.51 . $2H_2O$, 20.92
Chrome alum....	$CrK(SO_4)_2+12Aq$	499.432	K_2O, 9.44 . Cr_2O_3, 15.22. SO_3, 32.05. Water of crystallization, 43.29
Cobalt.....	$CoSO_4$	155.04	CoO, 48.36 . SO_3, 51.64
Copper.....	$CuSO_4$	159.64	CuO, 49.84 . SO_3, 50.16
Copper, cryst....	$CuSO_4+5H_2O$	249.72	CuO, 31.86 . SO_3, 32.07 H_2O, 36.07
Ferric.....	$Fe_2(SO_4)_3$	399.89	Fe_2O_3, 39.93 . SO_3, 60.07
Ferrous cryst....	$FeSO_4+7H_2O$	278.022	FeO, 25.84 . SO_3, 28.80 . H_2O, 45.36
Lead.....	$PbSO_4$	303.17	PbO, 73.59 . SO_3, 26.41 . (Pb, 68.31)
Lithium.....	Li_2SO_4	109.95	Li_2O, 27.18 . SO_3, 72.82
Magnesium.....	$MgSO_4$	120.39	MgO, 33.49 . SO_3, 66.51
Manganese.....	$MnSO_4$	151.00	MnO, 46.97 . SO_3, 53.03
Mercuric.....	$HgSO_4$	296.66	HgO, 73.01 . SO_3, 26.99
Mercurous.....	Hg_2SO_4	497.26	Hg_2O, 83.90 . SO_3, 16.10

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
Nickel.....	$NiSO_4$	154.75	NiO, 48.26 . SO_3, 51.74
Potassium, 1st...	$KHSO_4$	136.178	K_2O, 34.59 . H_2O, 6.61 . SO_3, 58.80
Potassium, 2nd..	K_2SO_4	174.27	K_2O, 54.05. SO_3, 45.95
Potassium alum..	$KAl(SO_4)_2$	258.34	K_2O, 18.24 . Al_2O_3, 19.78 . SO_3, 61.98
K alum cryst....	$KAl(SO_4)_2+12Aq$	474.532	K_2O, 9.93 . Al_2O_3, 10.77 SO_3, 33.74. Water of crystallization, 45.56
Silver.....	Ag_2SO_4	311.83	Ag_2O, 74.32 . SO_3, 25.68
Sodium, primary.	$NaHSO_4$	120.078	Na_2O, 25.82 . H_2O, 7.50 . SO_3, 66.68
Sodium, 2nd.....	Na_2SO_4	142.07	Na_2O, 43.64 . SO_3, 56.36
Sodium, cryst....	Na_2SO_4+10Aq	322.23	Na_2O, 19.24 . H_2O, 55.91 . SO_3, 24.85
Strontium.....	$SrSO_4$	183.70	SrO, 56.41 . SO_3, 43.59
Zinc.....	$ZnSO_4$	161.44	ZnO, 50.40 . SO_3, 49.60
Zinc, cryst.....	$ZnSO_4+7Aq$	287.552	ZnO, 28.30 . (H_2O, 43.85) . SO_3, 27.85
SULPHIDES.			
Hydrogen.....	H_2S	34.086	H, 5.92 . S, 94.08
Ammonium.....	$(NH_4)_2S$	68.154	$(NH_4)_2$, 52.95 . S, 47.05 . ($2NH_3$, 50.01) . H_2S, 49.99
Antimony.....	Sb_2S_3	336.61	Sb, 71.42 . S, 28.58
Arsenic.....	As_2S_3	246.13	As, 60.91 . S, 39.09
Bismuth.....	Bi_2S_3	512.21	Bi, 81.22 . S, 18.78
Cadmium.....	CdS	144.47	Cd, 77.80 . S, 22.20
Calcium.....	CaS	72.14	Ca, 55.54 . S, 44.46
Cuprous.....	Cu_2S	159.21	Cu, 79.86 . S, 20.14
Cupric.....	CuS	95.64	Cu, 66.47 . S, 33.53
Ferric (di).....	FeS_2	119.98	Fe, 46.54 . S, 53.46
Ferrous.....	FeS	87.91	Fe, 63.52 . S, 36.48
Lead.....	PbS	239.17	Pb, 86.59 . S, 13.41
Manganese.....	MnS	87.00	Mn, 63.14 . S, 36.86
Mercuric.....	HgS	232.67	Hg, 86.22 . S, 13.78
Molybdenum....	MoS_2	160.14	Mo, 59.96 . S, 40.04
Molybdenum....	MoS_3	192.21	Mo, 49.95 . S, 50.05
Nickel.....	NiS	90.75	Ni, 64.66 . S, 35.34
Potassium.....	K_2S	110.27	K, 70.92 . S, 29.08
Silver.....	Ag_2S	247.83	Ag, 87.06 . S, 12.94
Sodium.....	Na_2S	78.07	Na, 58.92 . S, 41.08
Zinc.....	ZnS	97.44	Zn, 67.09 . S, 32.91

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TABLE III.—*Continued.*

Names.	Formulæ.	Molar Wts.	Percentage Composition.
SULPHITES.			
Hydrogen.....	H_2SO_3	82.086	H_2O, 21.95 . SO_2, 78.05
Ammonium, 1st..	NH_4HSO_3	99.12	$(NH_4)_2O$, 26.27 . H_2O, 9.09 . SO_2, 64.64 (NH_3, 17.18 . H_2O, 18.18)
Ammonium, 2nd.	$(NH_4)_2SO_3$	116.154	$(NH_4)_2O$, 44.84 . SO_2, 55.16 . (NH_3, 29.33 . H_2O, 15.51)
Potassium.....	$KHSO_3$	120.178	K_2O, 39.19 . H_2O, 7.49 . SO_2, 53.32
Potassium, 2nd..	K_2SO_3	158.27	K_2O, 59.52 . SO_2, 40.48
Silver.....	Ag_2SO_3	295.83	Ag_2O, 78.34 . SO_2, 21.66
Sodium, primary.	$NaHSO_3$	104.078	Na_2O, 29.79 . H_2O, 8.65 . SO_2, 61.56
Sodium, 2nd.....	Na_2SO_3	126.07	Na_2O, 49.18 . SO_2, 50.82
THIOSULPHATES.			
Sodium.....	$Na_2S_2O_3$	158.14	Na_2O, 39.21 . S_2, 40.56 . O_2, 20.23
TUNGSTATES.			
Calcium.....	$CaWO_4$	288.07	CaO, 19.47 . WO_3, 80.53

The above data are calculated from the "International" atomic weights of 1912.

TABLE IV.—SPECIFIC GRAVITIES, MELTING POINTS (CENTIGRADE), ATOMIC VOLUMES AND SPECIFIC HEATS OF MOST OF THE ELEMENTS.

Elements.	Sp. Gr.	M. P.	At. Vol.	Sp. Heat.	$t°$ Cent.
Aluminum.....	2.58	657	10.50	0.214	60
Antimony.....	6.71	450	17.91	0.0508	55
Arsenic.....	5.73	*	13.08	0.0814	55
Barium.....	3.6	Red heat	38.16	0.049†	...
Bismuth.....	9.9	265	21.01	0.0308	55
Boron.....	2.63	Not det.	4.18	0.366	233
Bromine.....	3.18	−7.3	25.13	0.0843	−51
Cadmium.....	8.6	320	13.07	0.0548	50
Cæsium	1.87	26.5	71.07	Not det.	...
Calcium.....	1.6	800	25.05	0.170	50
Carbon (diamond).....	3.5	Not det.	3.43	0.467	978
Carbon (graphite).....	2.25	Not det.	....	0.500	1000
Carbon (charcoal).....	1.45+	Not det.	....	....	...

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TABLE IV.—*Continued.*

Elements.	Sp. Gr.	M. P.	At. Vol.	Sp. Heat.	t^{o} Cent.
Cerium	6.72	500?	20.87	0.0448	49
Chlorine	1.56[a]	....	22.7	0.1241[b]	...
Chromium	6.8	1720	7.66	0.100	36
Cobalt	8.9	1500	6.62	0.107	55
Copper	8.9	1080	7.14	0.952	58
Fluorine	....	....	12.7?	Not det.	...
Gallium	5.9	30	11.86	0.079	17
Germanium	5.47	900	13.25	0.077	?
Glucinum	1.8	Not det.	5.05	0.397[c]	20
Gold	19.32	1060	10.21	0.032	55
Hydrogen	0.07	....	14.3?	0.99[d]	...
Hydrogenium	0.62[e]	....	1.6?	....	...
Indium	7.4	176	15.54	0.057	50
Iodine	4.95	114	25.65	0.054	59
Iridium	22.4	1950	8.62	0.033	60
Iron (pure)	7.85	1503	7.11	0.1124	31
Iron (wrought)	8 (ave)	1400	....	....	...
Iron (cast)	var.	1050+	....	....	...
Lanthanum	6.16	Not det.	22.55	0.045	50
Lead	11.37	300	18.21	0.314	34
Lithium	0.59	180	11.76	0.941	64
Magnesium	1.74	700	13.98	0.245	36
Manganese	8.00	1800+	6.87	0.122	55
Mercury	13.59	−39.5	14.76	0.032	−59
Molybdenum	8.6	1750	11.16	0.072	55
Nickel	9.1	1427	6.44	0.108	55
Nitrogen	0.885	....	?[f]	0.237	...
Osmium	22.48	2500?	8.50	0.031	60
Oxygen	1.124	....	?[f]	0.217	13 to 200
Palladium	11.5	1400	9.26	0.059	55
Phosphorus	1.83	44.4	16.96	0.174	?
Phosphorus (red)	2.19	§	14.16	0.170	67
Platinum	21.5	1710	9.07	0.032	55
Potassium	0.87	62.5	44.94	0.166	−34
Rhodium	12.1	2000	8.51	0.058	?
Rubidium	1.53	38.5	55.9	0.075	?
Ruthenium	12.3	1800	8.27	0.061	?
Selenium	4.8	217	16.5	0.076	59
Silicon	2.49	1300	11.36	0.203	232
Silver	10.5	960	10.27	0.057	55
Sodium	0.97	96	23.71	0.293	−14
Strontium	2.5	Red heat	35.04	0.078?†	...
Sulphur	2.07	114.5	15.5	0.178	67
Tantalum	10.8	2300	16.7	Not det.	...

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TABLE IV.—*Continued.*

Elements.	Sp. Gr.	M. P.	At. Vol.	Sp. Heat.	$t°$ Cent.
Tellurium	6.4	452	19.9	0.047	55
Thallium	11.8	290	17.3	0.0335	58
Thorium	11.0	293.9	21.14	0.0276	50
Tin	7.3	232	16.3	0.056	50
Titanium	3.59	2600?	13.4	0.129	?
Tungsten	19.0	3000?	9.68	0.033	55
Uranium	18.7	1500	12.75	0.0277	49
Vanadium	5.5	1800	9.27	Not det.	...
Zinc	7.1	419	9.27	0.0935	50
Zirconium	4.15	Not det.	21.8	0.066	50

Certain elements have had specific gravities, hence atomic volumes, attributed to them from their positions in the "periodic" scale. Thus:

	Sp. gr.	At. vol.
Scandium	2.6	17
Columbium	7.0	13
Yttrium	3.6	25

Some of the high temperatures in the above table are mere approximations.

The last column is temperature at which the specific heat determinations were made.

In the sp. gr. column figures are given for crystallized condition when there is any appreciable difference between that and the amorphous state. In metals the highest sp. gr., usually that of the metal hammered or drawn into wire, is chosen.

All degrees are centigrade.

Boron and carbon have never been fused.

* Arsenic melts only under high pressure.

† The specific heats of Ba and Sr are not known by direct determination.

§ Red phosphorus when rapidly heated changes to normal at about 260° C.

[a b] 1.56 is sp. gr. of liquefied chlorine. Figure given for sp. heat is as referred to = vol. of water as unity. This is at constant *pressure* and at *minus* 200°. At constant *volume* the figure becomes 0.0928.

[c] Glucinum, sp. heat at 100° = 0.47. At 257° = 0.58.

[d] 0.07 is sp. gr. of liquefied hydrogen. The sp. heat 0.99 is referred to = vol. of air as unity. With = wt. of water as unit it would be 2.4.

[e] "Hydrogenium." Hypothetical element as in alloys (Palladium, etc.).

[f] Theory would give as rough values for solid "N" and "O" as follows: "N," sp. gr. = 3, at. vol. = 5. "O," sp. gr. = 2, at. vol. = 8. A similar "guess" would make fluorine about sp. gr. 1.5, with at. vol. about as in the table.

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TABLE V.—GASES AND VAPORS. THEIR FORMULÆ, DENSITIES, SPECIFIC GRAVITIES (AIR = 1) AND WEIGHT IN GRAMS PER LITER.

Names.	Formulæ.	Mol. Wt. or Density.	Sp. Gr. (Air = 1).	Wt. of 1 Liter.
Air	....	....	1.000	1.293
Argon	A	39.88	1.376	1.780
Arsenic	As_4	299.84	10.353	13.386
Bromine	Br_2	159.84	5.521	7.139
Chlorine	Cl_2	70.92	2.448	3.165
Fluorine	F_2	38.00	1.312	1.696
Helium	He	3.99	0.139	0.179
Hydrogen	H_2	2.016	0.070	0.089
Iodine	I_2	253.84	8.768	11.337
Mercury	Hg	200.60	6.906	8.929
Nitrogen	N_2	28.02	0.967	1.251
Oxygen	O_2	32.00	1.106	1.430
Phosphorus	P_4	124.16	4.287	5.543
Sulphur	S_2	64.14	2.213	2.862
Cyanogen	C_2N_2	52.02	1.796	2.322
Hydrobromic acid	HBr	80.928	2.796	3.615
Hydrochloric acid	HCl	36.468	1.259	1.628
Hydrofluoric acid	HF	20.008	0.691	0.893
Hydriodic acid	HI	127.928	4.418	5.713
Hydrocyanic acid	HCN	27.018	0.933	1.206
Water	H_2O	18.016	0.622	0.804
Hydric sulphide	H_2S	34.086	1.176	1.521
Hydric selenide	H_2Se	81.216	2.804	3.626
Hydric telluride	H_2Te	129.616	4.475	5.786
Ammonia	NH_3	17.034	0.588	0.760
Stibine	SbH_3	123.224	4.254	5.501
Arsine	AsH_3	77.984	2.693	3.481
Phosphine	PH_3	34.064	1.177	1.521
Carbon oxide	CO	28.00	0.967	1.250
Carbon dioxide	CO_2	44.00	1.519	1.964
Carbon bisulphide	CS_2	76.14	2.628	3.398
Carbon oxysulphide	COS	60.07	2.073	2.681
Carbonyl chloride	$COCl_2$	98.92	3.415	4.415
Methane	CH_4	16.032	0.554	0.716
Acetylene	C_2H_2	26.016	0.878	1.161
Ethelyne	C_2H_4	28.032	0.968	1.251
Ethane	C_2H_6	30.048	1.037	1.341
Propane	C_3H_8	44.064	1.521	1.967
Butane	C_4H_{10}	58.08	2.005	2.593
Benzol	C_6H_6	78.048	2.695	3.484
Nitrous oxide	N_2O	44.02	1.520	1.965
Nitric oxide	NO	30.01	1.036	1.340
Nitrosyl chloride	NOCl	65.47	2.260	2.922

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TABLE V.—*Continued.*

Names.	Formulæ.	Mol. Wt. or Density.	Sp. Gr. (Air = 1).	Wt. of 1 Liter.
Sulphur dioxide	SO_2	64.07	2.212	2.860
Sulphur dichloride	S_2Cl_2	135.06	4.662	6.028
Chlorous oxide	Cl_2O	86.92	3.000	3.879
Chloric oxide	ClO_2	67.46	2.329	3.011
Chromium oxychloride	CrO_2Cl_2	155.02	5.352	6.920
Boron tri-fluoride	BF_3	68.00	2.348	3.036
Arsenic tri-chloride	$AsCl_3$	181.34	6.261	8.096
Phosphorus tri-chloride	PCl_3	137.42	4.744	6.135
Silicon fluoride	SiF_4	104.30	3.605	4.661
Phosphorus pentafluoride	PF_5	126.04	4.352	5.627
Methyl alcohol	CH_3OH	32.032	1.106	1.430
Ethyl alcohol	C_2H_5OH	46.048	1.590	2.056
Ethyl ether	$(C_2H_5)_2O$	74.08	2.558	3.307
Methyl chloride	CH_3Cl	50.474	1.742	2.253
Ethyl chloride	C_2H_5Cl	64.49	2.227	2.879

The weight of any gas in this table, *per cubic foot, in grams*, may be figured by multiplying the figure in the last column by 28.32, since one cubic foot contains 28.32 liters.

Example.—Silicon fluoride, weight in grams of 1 liter = 4.661.

$$4.661 \times 28.32 = 132 = \text{grams per cubic foot.}$$

The weight in pounds avdp. per cubic foot may be obtained by multiplying figure in last column (*i.e.*, weight in grams of one liter) by 0.0624.

Example.—Propane, weight in grams of one liter = 1.967.

$$1.967 \times 0.0624 = 0.1227 = \text{lbs. per cubic foot.}$$

Several of the compounds in this table are liquid at ordinary temperatures, their weights *as gases* are the "theoretical" reductions to normal t° and pressure, not representing the true physical facts.

TABLE VI.—VOLUME AND SP. GR. OF WATER AT VARIOUS TEMPERATURES.

Temperature C°.	Specific Volume.	Specific Gravity.	Temperature C°.	Specific Volume.	Specific Gravity.
0°	1.0001324	0.9998676	18°	1.0012000	0.9986220
2°	1.0000320	0.9999680	20°	1.0017728	0.9982303
4°	1.0000000	1.0000000	22°	1.0022083	0.9977966
6°	1.0000320	0.9999680	26°	1.0032006	0.9968097
8°	1.0001241	0.9998759	36°	1.0063297	0.9937101
10°	1.0002730	0.9997271	38°	1.0070584	0.9929911
12°	1.0004756	0.9995246	50°	1.01200	0.98813
14°	1.0007292	0.9992713	100°	1.04327	0.95863
16°	1.0010314	0.9989697			

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100 vols. water at 0° yield 109 vols. ice at 0°. Sp. gr. of ice = 0.9173. One vol. water at 100° C. yields 1696 vols. steam at 100°.

Sp. gr. steam = 18.02 (O = 32), or 0.622 (air = 1). 1 liter weighs 0.59 gram.

Critical temp. of water + 370°, critical vol. = 2.33, critical pressure 195.5 atmospheres. (Critical temperature is same as "absolute boiling point.")

TABLE VII.—SPECIFIC GRAVITIES OF AQUA AMMONIA AT 15° CENTIGRADE.

Beaumé degrees.	Sp. gr.	Per cent. NH_3.	Beaumé degrees.	Sp. gr.	Per cent. NH_3.
10.0	1.000	0.00	19.2	0.938	16.22
10.3	.998	0.45	19.5	0.936	16.82
10.5	.996	0.91	19.9	0.934	17.42
10.7	.994	1.37	20.2	0.932	18.03
11.1	.992	1.84	20.5	0.930	18.64
11.4	.990	2.31	20.8	0.928	19.25
11.7	.988	2.80	21.1	0.926	19.87
11.9	.986	3.30	21.5	0.924	20.49
12.2	.984	3.80	21.8	0.922	21.12
12.5	.982	4.30	22.1	0.920	21.75
12.8	.980	4.80	22.5	0.918	22.39
13.1	.978	5.30	22.8	0.916	23.03
13.4	.976	5.80	23.1	0.914	23.68
13.7	.974	6.30	23.5	0.912	24.33
14.0	.972	6.80	23.8	0.910	24.99
14.2	.970	7.31	24.1	0.908	25.65
14.6	.968	7.82	24.5	0.906	26.31
14.9	.966	8.33	24.8	0.904	26.98
15.2	.964	8.84	25.2	0.902	27.65
15.5	.962	9.35	25.5	0.900	28.33
15.8	.960	9.91	25.9	0.898	29.01
16.1	.958	10.47	26.0	0.897	29.20
16.4	.956	11.03	26.2	0.896	29.69
16.7	.954	11.60	26.4	0.894	30.37
17.0	.952	12.17	26.9	0.892	31.05
17.3	.950	12.74	27.3	0.890	31.75
17.6	.948	13.31	27.6	0.888	32.50
17.9	.946	13.88	28.0	0.886	33.25
18.3	.944	14.46	28.3	0.884	34.10
18.6	.942	15.04	28.7	0.882	34.95
18.9	0.940	15.63			

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TABLE VIII.—SPECIFIC GRAVITY OF SULPHURIC ACID AT 15° CENTIGRADE.

Sp. gr.	Beaumé degrees.	% H_2SO_4	Sp. gr.	Beaumé degrees.	% H_2SO_4	Sp. gr.	Beaumé degrees.	% H_2SO_4
1.000	0	0.09	1.310	34.2	40.35	1.640	56.3	71.99
1.005	0.7	0.83	1.320	35.0	41.50	1.650	56.9	72.82
1.010	1.4	1.57	1.330	35.8	42.66	1.660	57.4	73.64
1.015	2.1	2.30	1.340	36.6	43.74	1.670	57.9	74.51
1.020	2.7	3.03	1.350	37.4	44.82	1.680	58.4	75.42
1.030	4.1	4.49	1.360	38.2	45.88	1.690	58.9	76.30
1.040	5.4	5.96	1.370	39.0	46.94	1.700	59.5	77.17
1.050	6.7	7.37	1.380	39.8	48.00	1.710	60.0	78.04
1.060	8.0	8.77	1.390	40.5	49.06	1.720	60.4	78.92
1.070	9.4	10.19	1.400	41.2	50.11	1.730	60.9	79.80
1.080	10.6	11.60	1.410	42.0	51.15	1.740	61.4	80.68
1.090	11.9	12.99	1.420	42.7	52.15	1.750	61.8	81.56
1.100	13.0	14.35	1.430	43.4	53.11	1.760	62.3	82.44
1.110	14.2	15.71	1.440	44.1	54.07	1.770	62.8	83.32
1.120	15.4	17.01	1.450	44.8	55.03	1.780	63.2	84.50
1.130	16.5	18.31	1.460	45.4	55.97	1.790	63.7	85.70
1.140	17.7	19.61	1.470	46.1	56.90	1.800	64.2	86.90
1.150	18.8	20.91	1.480	46.8	57.83	1.810	64.6	88.30
1.160	19.8	22.19	1.490	47.4	58.74	1.820	65.0	90.05
1.170	20.9	23.47	1.500	48.1	59.70	1.825	65.2	91.00
1.180	22.0	24.76	1.510	48.7	60.65	1.830	65.5	92.10
1.190	23.0	26.04	1.520	49.4	61.59	1.835	65.7	93.43
1.200	24.0	27.32	1.530	50.0	62.53	1.840	65.9	95.60
1.210	25.0	28.58	1.540	50.6	63.43	1.8405	....	95.95
1.220	26.0	29.84	1.550	51.2	64.26	1.8410	....	97.00
1.230	26.9	31.11	1.560	51.8	65.08	1.8415	....	97.70
1.240	27.9	32.28	1.570	52.4	65.90	1.8410	....	98.20
1.250	28.8	33.43	1.580	53.0	66.71	1.8405	....	98.70
1.260	29.7	34.57	1.590	53.6	67.59	1.8400	....	99.20
1.270	30.6	35.71	1.600	54.1	68.51	1.8395	....	99.45
1.280	31.5	36.87	1.610	54.7	69.43	1.8390	....	99.70
1.290	32.4	38.03	1.620	55.2	70.32	1.8385	....	99.95
1.300	33.3	39.19	1.630	55.8	71.16			

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TABLE IX.—SPECIFIC GRAVITY OF HYDROCHLORIC (MURIATIC) ACID. 15° CENTIGRADE.

Sp. gr.	Beaumé degrees.	% HCl.	Sp. gr.	Beaumé degrees.	% HCl.	Sp. gr.	Beaumé degrees.	% HCl.
1.000	0.0	0.16	1.075	10.0	15.16	1.145	18.3	28.61
1.005	0.7	1.15	1.080	10.6	16.15	1.150	18.8	29.57
1.010	1.4	2.14	1.085	11.2	17.13	1.152	19.0	29.95
1.015	2.1	3.12	1.090	11.9	18.11	1.155	19.3	30.55
1.020	2.7	4.13	1.095	12.4	19.06	1.160	19.8	31.52
1.025	3.4	5.15	1.100	13.0	20.01	1.163	20.0	32.10
1.030	4.1	6.15	1.105	13.6	20.97	1.165	20.3	32.49
1.035	4.7	7.15	1.110	14.2	21.92	1.170	20.9	33.46
1.040	5.4	8.16	1.115	14.9	22.86	1.171	21.0	33.65
1.045	6.0	9.16	1.120	15.4	23.82	1.175	21.4	34.42
1.050	6.7	10.17	1.125	16.0	24.78	1.180	22.0	35.39
1.055	7.4	11.18	1.130	16.5	25.75	1.185	22.5	36.31
1.060	8.0	12.19	1.135	17.1	26.70	1.190	23.0	37.23
1.065	8.7	13.19	1.140	17.7	27.66	1.195	23.5	38.16
1.070	9.4	14.17	1.142	18.0	28.14	1.200	24.0	39.11

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TABLE X.—SPECIFIC GRAVITY OF NITRIC ACID AT 15° C.
(Compare Water at 4° C.)

Sp. gr.	Bé.	% HNO_3	Sp. gr.	Bé.	% HNO_3	Sp. gr.	Bé.	% HNO_3	Sp. gr.	Bé.	% HNO_3
1.000	0.0	0.10	1.155	19.3	25.60	1.310	34.2	49.07	1.465	45.8	81.42
1.005	0.7	1.00	1.160	19.8	26.36	1.315	34.6	49.89	1.470	46.1	82.90
1.010	1.4	1.90	1.165	20.3	27.12	1.320	35.0	50.71	1.475	46.4	84.45
1.015	2.1	2.80	1.170	20.9	27.88	1.325	35.4	51.53	1.480	46.8	86.05
1.020	2.7	3.70	1.175	21.4	28.63	1.330	35.8	52.37	1.485	47.1	87.70
1.025	3.4	4.60	1.180	22.0	29.38	1.335	36.2	53.22	1.490	47.4	89.60
1.030	4.1	5.50	1.185	22.5	30.13	1.340	36.6	54.07	1.495	47.8	91.60
1.035	4.7	6.38	1.190	23.0	30.88	1.345	37.0	54.93	1.500	48.1	94.09
1.040	5.4	7.26	1.195	23.5	31.62	1.350	37.4	55.79	1.501	....	94.60
1.045	6.0	8.13	1.200	24.0	32.36	1.355	37.8	56.66	1.502	....	95.08
1.050	6.7	8.99	1.205	24.5	33.09	1.360	38.2	57.57	1 503	....	95.55
1.055	7.4	9.84	1.210	25.0	33.82	1.365	38.6	58.48	1.504	....	96.00
1.060	8.0	10.68	1.215	25.5	34.55	1.370	39.0	59.39	1.505	48.4	96.39
1.065	8.7	11.51	1.220	26.0	35.28	1.375	39.4	60.30	1.506	....	96.76
1.070	9.4	12.33	1.225	26.4	36.03	1.380	39.8	61.27	1.507	....	97.13
1.075	10.0	13.15	1.230	26.9	36.78	1.385	40.1	62.24	1.508	48.5	97.50
1.080	10.6	13.95	1.235	27.4	37.53	1.390	40.5	63.23	1.509	....	97.84
1.085	11.2	14.74	1.240	27.9	38.29	1.395	40.8	64.25	1.510	48.7	98.10
1.090	11.9	15.53	1.245	28.4	39.05	1.400	41.2	65.30	1.511	....	98.32
1.095	12.4	16.32	1.250	28.8	39.82	1.405	41.6	66.40	1.512	....	98.53
1.100	13.0	17.11	1.255	29.3	40.58	1.410	42.0	67.50	1.513	....	98.73
1.105	13.6	17.89	1.260	29.7	41.34	1.415	42.3	68.63	1.514	....	98.90
1.110	14.2	18.67	1.265	30.2	42.10	1.420	42.7	69.80	1.515	49.0	99.07
1.115	14.9	19.45	1.270	30.6	42.87	1.425	43.1	70.98	1.516	....	99.21
1.120	15.4	20.23	1.275	31.1	43.64	1.430	43.4	72.17	1.517	....	99.34
1.125	16.0	21.00	1.280	31.5	44.41	1.435	43.8	73.39	1.518	....	99.46
1.130	16.5	21.77	1.285	32.0	45.18	1.440	44.1	74.68	1.519	....	99.57
1.135	17.1	22.54	1.290	32.4	45.95	1.445	44.4	75.98	1.520	49.4	99.67
1.140	17.7	23.31	1.295	32.8	46.72	1.450	44.8	77.28			
1.145	18.3	24.08	1.300	33.3	47.49	1.455	45.1	78.60			
1.150	18.8	24.84	1.305	33.7	48.26	1.460	45.4	79.98			

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PART II

CALCULATION OF FURNACE CHARGES

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CALCULATION OF FURNACE CHARGES.

By the calculation of a furnace charge is usually meant the adjustment by computation of fluxes to the ore (and sometimes to the ash of the fuel) in a smelting furnace, so as to secure, so far as calculation goes, the formation of a slag of required composition.

It is rarely possible to figure the outcome with precision, even granting the conditions of good sampling and smooth running.

The best approach to theoretical results is found in iron smelting. The reason is obvious enough. The only "variants" in this case are:

1. The iron which may enter the slag.
2. Variation in amount of silica which may enter the metal, as silicon.

It is otherwise in lead and copper smelting, where the difficulties of fumes and of the absorption of undesired metal in the slag are complicated by very uncertain factors such as the oxidation of sulphides to a degree greater or less than estimated.

The total absence of "matte" from the iron furnace—nothing being allowed to enter the charge which goes to the formation of that product, constitutes of itself a simplification sufficient to make a "class" of iron smelting as distinct from that of any metal whose ores are charged wholly or partly as sulphides.

Although it is not possible to dispense with intelligent calculations for slag and matte formation, nothing but special experience at a given plant and on given ores and fuel can enable the practitioner to "discount" the inevitable variations.

This fact has been made the basis for countless sneers against the scientific calculation of metallurgical operations. The novice will often be assured that a certain "run" was made without any computation of charges, and numberless are the tales told of the "theorist" who spent a week in calculating his charge and then froze his furnace the first day.

This means that there are many things to learn about smelting other than the computation of correct charges.

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That a "run" was made without any calculation may be absolutely true. If the average composition of the material is fairly constant, there is no reason why a charge once established should not continue to serve for an indefinite time. Also to quote from Professor Peters in his "Copper Smelting," "It is almost as hard to damage an improving furnace as it is to better a sickly one." Under first class conditions, then, a considerable variation in slag composition may take place without damage.

Nevertheless there is no better safeguard against mishaps other than those purely mechanical, than a knowledge, clean-cut and scientific, of what you are working for, and of the material with which you are to accomplish your object.

It is futile to pretend that you have any such knowledge unless you are clear as to the composition of your charges, and the theory upon which you are mixing them.

Gone, let us hope, are the days of the old rule: "A lot of ore, a lot of coke, and about a quarter of a lot of limestone."

The author confesses to having seen certain iron furnaces run upon this luminous dictum. He feels bound to add that it was "several" years ago.

By a "slag" is always meant a fusible silicate. No other case at least is considered in these pages.

By a "flux" is meant any substance which, added to a charge, produces fluidity, usually by chemical combination with certain non-metallic ingredients of the ore.

However, an ore may be "self-fluxing." That is, no additions, such as limestone or iron oxide, are needed for successful smelting. In such a case the "flux" is still present, but as a constituent of the ore instead of an artificial addition to it.

A "matte" is a combination of metals with sulphur (also to a less extent with other elements) which settles under the slag in the hearth.* It is frequently the only commercial product of a furnace.

A "speiss" is a basic arsenide of iron, often containing a variety of other metals also. It forms under the same conditions as "matte." Speculations, however interesting as to the

* That is to say, which should do so.

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essential nature and composition of matte, are out of place in this work.

The "charge" of a furnace includes ore, fuel and fluxes. When the composition of all of these is known, we may roughly determine in advance what portions of each will go into metal, matte, slag, fumes or gases.*

Complete "reduction" implies the elimination of the non-metallic portion of a compound, and the production of the metal as such.

$$2PbO + C = 2Pb + CO_2$$

According to this equation the lead oxide is "reduced" and the carbon is "oxidized," the chemical operation being in fact a mere transfer of oxygen. Metallurgically such an operation is spoken of as "reduction," since the "reduced" product (the metallic lead) is the commercial one.

A "matte," although its formation is usually accompanied by both oxidizing and reducing agencies, is properly the resultant of neither. It may be either a "residual" or a direct union compound. For example (1st case):

$$2CuS + O_2 = Cu_2S + SO_2$$

Or, by merely heating:

$$2CuS \text{ (heated)} = Cu_2S + S$$

Here the matte (Cu_2S) may be called a "residual" compound, being what is left of the cupric sulphide after the reaction is over.

2nd case: $2Fe_2O_3 + 7PbS = 7Pb + 4FeS + 3SO_2$

Here the matte (FeS) is evidently no mere "residual," but is formed by a complex chemical interchange.

Let us suppose that we are to smelt a partly roasted (oxidized) ore, containing lead sulphide, zinc sulphide and some oxides of both of these metals, also iron pyrites (FeS_2) copper and silica.

We have limestone ($CaCO_3$) for flux, also hematite (Fe_2O_3).

* By "fumes" we understand substances dissipated in a gaseous state, but condensing to solids at ordinary temperatures (*e.g.*, PbO; ZnO).

Gases proper do not condense at ordinary temperatures. The usual gaseous products of a furnace are known as "permanent" gases (CO_2; SO_2).

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The fuel may be taken as simply carbon.

Special cases with figures will be found later. We have here merely to indicate the general problem, which is to estimate which of these constituents will yield metal, and which matte, slag, fumes or gases. The case is introduced chiefly to point out the somewhat indeterminate nature of the problem, showing that it is not practicable to make accurate predictions as to the relative proportions of these products.

Let us take them singly.

Metal.—Lead is supposed to be the only metallic product here, the theory of the operation being to get all of that metal, *as* metal, while the copper and other elements go into the matte. But no smelting operation will reduce *all* the lead, or at least will not bring it all on the hearth as metallic lead. Some of it will remain in the matte as sulphide, a little will go into the slag, and a variable amount will be dissipated as fumes, either lost or collected as "flue-dust." We start, then, with elements of uncertainty in our calculation-data. If the assumption is made, however, that the whole of the lead will be "tapped," our calculations will not be materially affected.

Matte.—This is a difficult product to figure, regarding probable correspondence of computations to results. It is a very easy matter to throw together (in our calculations) the supposed elements which might go to matte formation, if that were all. For example, take all of the sulphur with so much of the metals as might be supposed to meet chemical formulæ rationally, but this will not do, for there are influences at work to modify so simple a process as the "melting down" of the sulphur with its chosen proportion of metals, to form the matte.

Study of these would lead us astray. We may mention only the variable oxidation of the blast, controlled by temperature, pressure, shape of the furnace and composition of the charge. These variations may result in greater or less oxidation of sulphur and of metals, thus causing change in ratio of matte and slag. It is evident that the more oxidation of metals takes place the more probable it is that these will find their way into the slag instead of the matte. This is often the desired result as to iron, it may be to a limited extent as to zinc, but copper is of course too valuable to waste in the slag, and whether the

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operation be one for metal and matte, or for matte alone, copper is always desired in the latter.

Various rules have been given for estimation of composition and amount of matte, *i.e.*, in advance of the operation. Thus Professor Peters in his "Modern Copper Smelting," tenth edition, page 82, says:

"Taking the contents of copper in the charge as a standard for comparison, sufficient sulphur should be allotted to it to form a subsulphide, excess of sulphur remaining being supplied with sufficient iron to form monosulphide of that metal. If other metals are present, such as lead, zinc or manganese, three-fourths of the former, one-half of the second, or one-fourth of the latter substance may be first considered as forming a monosulphide with the sulphur. . . . If the rate of smelting be slow and considerable lime or magnesia be present, 5 per cent. of the sulphur should be deducted before beginning the calculation; and if the furnace is a reverberatory the resulting matte will average 8 per cent. higher in copper than is found by this formula."

Calculations on similar rules will be found among the illustrations.

This calculation, viz: estimating the amounts of metal in matte by combination with sulphur, and then removing the whole combination from subsequent consideration, is called "taking out the matte," and is a necessity in slag calculation.* *What remains after the matte is "taken out" is the basis for slag computation.* There are cases where no matte is "taken out;" these are confined to iron smelting or to those rare cases in other metals where sulphur is entirely absent.

Slag.—Having disposed of these subtractions of metal (if there is any to be allowed for) and matte, the remaining elements, so far as they are solids, are to be combined into a "slag." Illustrations of the procedure will be found in the pages following. Since the subtractions for metal or matte are from the ore alone, no figuring on slag is attempted until these subtractions have been made, so that, practically, "slag calculation"

* The above quotation from Professor Peters' work applies to smelting for copper matte, not at all to smelting on "lead basis" with matte as an incidental. Practitioners, however, regard their own trial runs as of far greater importance than any set "rules" for matte estimation.

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is made not (as a rule) upon the original ore, but only upon the ore "prepared" (on paper) for the calculation, *by the elimination of all except its slagging constituents.*

Fumes.—Probably no metallurgist would attempt to "figure out" in advance the losses by fumes. It has been elsewhere said that in actual running the results by analysis of matte and slag may indicate, although somewhat roughly, the fume losses. These may be important enough to lead to re-calculation of charges.

Fumes may include oxides of lead, zinc, arsenic and several other metals. It is a matter of common knowledge that many substances not particularly volatile in themselves will be carried, and that in no inconsiderable quantities, by more volatile compounds. The phenomenon is by no means confined to smelting operations, but is well known to every laboratory chemist.

Certain compounds of gold, when heated by themselves, decompose readily, the non-metal dissipating, the gold remaining behind. Mix the same compound of gold with others which are entirely volatile, the curious phenomenon is now presented of the gold compound partly resisting decomposition, so that gold will be found in very notable quantity in the collected fumes.

The same is true of every metal. It is useless, then, to assume that a certain constituent will not be found in the fumes, so far as the mere fact goes that it is not *of itself* volatile. Here we have a factor even more uncertain than matte, in forming our estimates.

Gases.—Gases are mainly formed in two ways, first, from combustion of the fuel, and second, from expulsion of carbonic acid gas from limestone. We have also, in many cases, SO_2 gas from combustion of sulphur. They present no obstacles in any case to slag computation. Assume, whenever limestone is charged, that all of its evolved gas is "out" of the computation. Silica unites with CaO. Gas escapes.

The present treatise being almost wholly confined to calculations for slags already assumed, we do not go into the physical properties of their numerous varieties. It is fairly presumable that any person who has use for slag calculations has at hand sufficient data of either reference or experience to know what he should figure for.

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There are, however, certain considerations which must be taken into account, on the physical side, brief mention of which is not altogether out of place.

Fusibility is the chief desideratum. As for fusibility at a stated temperature, it is evident that in an iron furnace, with temperature hundreds of degrees above that of any matting or lead furnace, the question of temperature in relation to slag fusion is less important. Hence a very great variation in silica percentage is allowable. No general rule can apply except the statement that nice adjustment of fusibility to estimated temperature is not a practicable idea, but that when it is known that the temperature, from whatever causes, will be low, slags of low-fusion point should be figured for.

Here may come in a complication. Fusibility is not the only requisite. If the more fusible of two possible slags should also be much the heavier, the question of separation of the matte becomes important. It is obvious that separation, *other things being equal*, will be better accomplished when there is a marked difference in specific gravity between slag and matte. Broadly, the more iron oxide, the heavier the slag, while lime lightens it. Unfortunately, iron usually adds fusibility.

Unfortunately, that is, as regards conflict between two desirable properties. The metallurgist has not unfrequently to decide between two slags one of which is the lighter, the other the more fusible.

Still another consideration comes in, in matte separation. It has been remarked * that an "acid" (siliceous) slag lets fall a matte better than an equally light and much "thinner" basic slag, *containing principally alkaline and earthy bases.*

The combination of these principles for the effective separation of slag and matte belongs to the tentative practice of actual operations.

The special conditions of heat and blast, with probably several others, come in to modify slag practice. Rare, indeed, would be the case in which it would be possible to establish all of these conditions in advance.

* Peters' "Modern Copper Smelting," page 231, tenth edition. The observation is also found elsewhere, though I am unable to quote the work.

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In charge calculations we shall assume one hundred pounds of ore as basis of computation. This has been objected to on the grounds (1) of "custom," (2) of "difficulty."

If a "custom" is good it should be retained; if bad, it should be dropped.

As to "difficulty," it is both easier and safer to figure on the 100 basis, and afterward multiply by whatever factor is called for.

This applies especially to our method of "representative equations."

As for starting with "total" charge and then subdividing into ore, fuel and flux, it is so much more "difficult" that argument is uncalled for.

The methods of slag calculation (furnace charges) hitherto used seem to the author to lack generality. However, before introducing a general method, we demonstrate the usual calculation by excess and deficiency. The substance of this has already been given in the stoichiometric part of the work.

A few tables of silicates familiar to all metallurgists are given, as reference matter, also some problems hardly to be classified under any heading in Part I.

Slags having been roughly divided (on the arithmetical side) as either "formulistic" or "percentage," we here point out that while every formula can be readily transformed into a percentage analysis, the converse of this proposition is rarely true.

Nevertheless, the best "recipes" which state percentages are either directly derived from formulistic compounds (Problem III) or they are close approximations to such formulæ.

Computations regarding excess, whether of one constituent over another in the same substance, or as adjustments of one material in the charge to another, have to do mainly with formulistic considerations. In the method finally recommended as the most general, the usage will be to settle upon the formula if such be demanded, *and then reduce to the "percentage" basis.*

In order to familiarize the student with the handling of chemical ratios some examples are introduced in advance of slag calculations proper. They involve metallurgical operations to some extent, but are given as exercises rather than as practical cases.

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No new principles are introduced. Every problem falls under one or another case already given.

The calculation of a charge may be made upon the sole basis of *percentages* of the ingredients of the resulting slag. But the student knowing no other method is ill equipped. He should not only recognize chemical relations, but should be ready to figure by their means, in any computation called for.

A few of the examples are purely "stoichiometric," having little connection with practical metallurgy, although involving reasoning of the same character. They will aid in apprehension of the elements of the subject, which are, by the way, easier to grasp and apply than is commonly supposed.

Slags are formulistically classed as "Singulo," "Bi-" and "Sesqui-" silicates.* These terms refer to the ratio of the oxygen in the silica to that in the bases.

Examples.—$2CaO,SiO_2$ is a singulo silicate because oxygen in silica *equals* oxygen in base.

CaO,SiO_2 is a bisilicate because oxygen in the silica is *double* that in the base.

In a sesqui-silicate the oxygen in the silica is *half as much again* as oxygen in the base. Thus: $4CaO,3SiO_2$.

Here we have four atoms of oxygen in the lime and six in the silica, *i.e.*, oxygen in silica is to oxygen in base as $1\frac{1}{2}$ to 1.

This nomenclature is a return to the old "dualistic" form of chemical formulæ. It might perhaps better be called a retention of it.

See problem III, "Given formula of a compound to deduce its analysis."

Modern forms of the above silicates would be:

$$Ca_2SiO_4;\ CaSiO_3;\ \text{and}\ Ca_4Si_3O_{10}$$

The old forms are far more convenient for the metallurgist, as they exhibit at a glance the oxygen relations of silica and base.

If, in the comparison of these forms, we so write the singulo and the bisilicate as to *equalize the bases*, their sum will then be a sesqui-silicate.

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* We have also, though rarely, some cases of "trisilicates."

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Example:

Singulo.....$2CaO + SiO_2$
"Bi" (formula doubled to equalize base).....$2CaO + 2SiO_2$

"Sesqui" (sum of the "singulo" and "bi")...$4CaO + 3SiO_2$

The example takes the same form as already given.

The singulo silicate is the commonest form. In the many cases where no formulæ are supposed to be figured on, but mere "percentages" of constituents are named as required, it will often be found that some "formula" was the original form. It is but a case under the problem adduced above.

It is often said that "in practice" slags are made more acid than formula calls for. They are indeed calculated to a higher percentage of silica at times, but this is to offset uncalculated bases, which come in to set the silica percentage back to its proper proportion.

As most of the metals entering into slags are bivalent, the formulæ usually show the arrangement as given above for lime. Alumina, however, has formula Al_2O_3, hence its silicates have the following formulæ:

Singulo.....$2Al_2O_3,3SiO_2$
Bi-.....$Al_2O_3,3SiO_2$
Sesqui-.....$4Al_2O_3,9SiO_2$

In these formulæ, if we reduce the ratio of oxygen in base to oxygen in silica to lowest terms we still have 1 : 1, 1 : 2, and 2 : 3 as ratios of oxygen in base to oxygen in silica.

It is usually practicable, with the ordinary choice of material available, to secure a slag which shall be "formulistic" so far as regards ratio of oxygen in base to oxygen in silica. But when it comes to a demand for a certain ratio *between bases*, still retaining the oxygen ratios, the condition is quite different, and often impossible.

See example a few paragraphs below.

In showing how to provide material for "excess" and to arrange charges for slags approaching within reasonable limits to the desired formula, we do not lose sight of the fact that we are chiefly interested in showing how to compute what we may term "percentage" slags.

We should be familiar with both methods of computation. We start with the formulistic idea, and in order not to confuse

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the student we do not at first introduce examples of mixed type.

Remember again that any formula may be put into analytical form, and that the transformation is made simply to facilitate calculation in the general or "representative" method, which, although we bring it last in order, *is the one recommended as of most universal application.*

We here present a case of "desired formula," giving the supposed material at command by analysis. It will be found that it is impossible to literally fulfil the theoretical requirement.

The method of calculation has been given, but in "Introductory Problems" a few pages ahead, the exact detail will be found, for which reason the case is not carried out in full, though results are indicated.

We want to produce a slag of the formula:

$$4FeO + 2CaO + 3SiO_2$$

This is a "singulo." Note, however, that the requirement does not end with this proviso. We have not only the formulistic fact that the weight of all oxygen in the bases equals that of all the oxygen in the silica, but the formula calls for *twice as many molecules of iron oxide* (FeO) *as of lime* (CaO).

The following are supposed to be the only available materials at command for the charge:

1. The ore, whose only slagging ingredients are: Silica 20 per cent., and FeO (or its equivalent in other form) also 20 per cent.

2. A limestone containing five per cent. of silica and fifty-three per cent. of lime (CaO).

First, then, calculate for a "singulo" as the formula requires.

The leading results of calculation are here given; the student may verify them as an exercise.

After adjusting SiO_2 and FeO *in the ore* in the required proportion by formula, we find silica excess 11.67. Adjusting also silica and lime *in the limestone* we get CaO excess 43.67. Finally we find that the limestone required will be almost exactly 50 lbs. (Ore 100.)

The slag produced will contain, for every 20 lbs. of iron oxide, no less than 26½ lbs. of CaO. It will, in short, be very far

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from the requirement of the formula, *although it will be a perfect "singulo."*

Suppose again that instead of adjusting CaO to the excess silica of the ore we took just enough limestone to yield CaO in the exact required proportion *to the iron.* Of course this could be very easily done, but the result would be that we should *no longer have a singulo silicate.* The *excess of silica* would now be a very material one over that requirement. In practice the metallurgist must now decide whether he will adhere to the "singulo" idea, or accept a more siliceous slag for the sake of the desired ratio between his bases. In all likelihood a compromise figure would be adopted, but discussions of this nature are endless, and we have assumed at the outset that they shall not be gone into to any extent.

This is a good point at which to call attention to the relation of the two oxides of iron. Slags are invariably figured as containing only the FeO form. Per contra, iron (other than sulphide) is introduced into the furnace as Fe_2O_3. To compare these, remember that we must first equalize the iron, comparing Fe_2O_3 with 2FeO:

Molecular weight of Fe_2O_3 = ...160
Molecular weight of 2FeO = ...144

160 : 144 = 10 : 9, so that to reduce the higher to the lower oxide (*i.e.*, in passing from analyses to slag calculations) it is only necessary to multiply the percentage of ferric oxide by 0.9 to obtain the percentage of ferrous oxide. This explanation of the reason for the factor 0.9 would hardly have found a place here but for the fact that we recently saw, in actual practice, the curious error of *forgetting the equalization* of the iron in comparing the two oxides arithmetically. The operator had forgotten the factor, and tried to regain it as above, with amazing result. A similar error in other cases of stoichiometrical calculations is by no means uncommon.

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INTRODUCTORY PROBLEMS.

(*a*) Ore has: Silica, 40 per cent.; alumina, 20 per cent. We are to calculate on a "singulo" basis, having a limestone analyzing: Silica, 10 per cent.; calcium carbonate, 90 per cent.

It is required to find what weight of limestone must be added to 100 lbs. of the ore, to form a lime-alumina silicate on above basis.

Solution.—We must first find silica excess in the ore itself on the "singulo" basis. Singulo silicate of alumina is $2Al_2O_3 + 3SiO_2$.

Refer here to the problems in excess and deficiency. The silica excess of the ore will be found to be *22. 36 per cent.*

We must next find the CaO excess in the limestone. Enough of the CaO must be taken out of the limestone *to satisfy its own silica,* before we can compute for the ore. In other words, we must get the *CaO excess* of the limestone, and compare it with the *SiO_2 excess* of the ore. Under the condition, this calculation of excess must be for the singulo form. (The method is illustrated for the lime here; it is of course the same as for the alumina above, where answer was given without operation.)

$$\begin{array}{cccccc} SiO_2 & : & 2CaO & = & \text{lbs. } SiO_2 & : & \text{lbs. CaO} \\ 60 & : & 112 & = & 10 & : & 18.66 \end{array}$$

But the total lime in the limestone is fifty-six per cent. of ninety per cent., that is, $90 \times .56 = 50.4$ per cent. CaO.

Lime required by silica in the limestone being 18.66 per cent., we have: $50.4 - 18.66 = 31.74$ = excess of CaO or "available" lime.

The problem is now reduced to this: An ore with 22.36 per cent. silica is to be "adjudicated" as to lime silicate with a limestone with 31.74 per cent. lime.

For the *alumina of the ore* is now out of the computation, having been set aside with its proper amount of silica in the first operation.

Also, the *silica of the limestone* is "out" of this final computation, having been set aside with its proper per cent. of lime.

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These quantities, being already in the proper singulo ratios, do not in the least disturb the calculation of the remaining portions of the ingredients, nor do they affect the correctness of the outcome, since that must be in "singulo" form.

Thus we have now to do only with *excess silica* on the one side and *excess lime* on the other. These are often called, as above, "available" quantities.

We adjust silica and lime as follows (remember that lime is 2CaO):

Silica : lime = excess silica : required lime
60 : 112 = 22.36 : 41.74

But we know that there is 31.74 available CaO in the limestone, and since the limestone is "100 per cent. of itself," we have:

$$31.74 : 100 = 41.74 : 131.5$$

It will, then, require *131.5 lbs. of the limestone* to satisfy 100 lbs. of the ore.

This, as a sort of "type" excess problem, has been detailed at great length. In future we shall take certain operations for granted.

(*b*) Suppose the ore of Problem (*a*) and the limestone to be fused together, the constituents mentioned being the only ones going to the formation of slag, what will be the analysis of the slag?

	Silica.	Alumina.	Lime.
From 100 lbs ore.....	40.00	20.00	....
From 131.5 lbs. limestone.....	13.15	....	66.27
	53.15	20.00	66.27

Sum of these weights = 139.42. We then have Problem III (*c*):

$$\frac{5315}{139.42} = 38.12 \text{ per cent. silica}$$

$$\frac{2000}{139.42} = 14.34 \text{ per cent. alumina}$$

$$\frac{6627}{139.42} = 47.53 \text{ per cent. lime}$$

Sum = 99.99 per cent.—proof.

The omitted operations are obvious. Similar proofs should always be made for safety.

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This is really a problem and its solution, in slag calculation, albeit a very simple one.

In "taking out" matte constituents, preparatory to computing for slag, the method is the same.

"Taking out" a matte, *i.e.*, calculating it in advance, means simply the estimation of matte composition on what is supposed to be the most probable chemical scheme of formation. The adjudication of elements having been made, the compounds thus (theoretically) formed are subtracted from the totals as given by analysis. The slag is computed from the remainder, with the aid of such other material as may be added.

That is, in the actual operation of smelting, the ingredients thus "taken out" do actually separate in the form of matte, so that they must be computed and subtracted before we can proceed to figure on the slag formation.

(*c*) A roasted ore contains:

Copper	4.5 per cent.
Iron	18.0 per cent.
Sulphur	6.0 per cent.

Assuming that the matte will consist of Cu_2S and FeS, also that there will be *no loss of sulphur*, how much iron will be left for slag formation?

It is always assumed that copper will take precedence of iron in matte formation, owing to its greater affinity for sulphur. Thus the proceeding will be to *first* calculate all of the copper into Cu_2S. *Second*, if any sulphur is left over, calculate it all into FeS. *Third*, having subtracted the iron required from total iron, we shall now have remaining the constituents of the original roasted ore, minus all the copper, and all the sulphur, and minus *so much of the iron as was found necessary to form matte.*

All of this is simply a case under Problems II (*c*) and V.

Solution.—In most cases a glance at the figures will show whether there is excess of a given constituent, unless the excess or deficiency is small. Here for example it is evident that there is more than enough sulphur for the copper, and more iron than will satisfy the remaining sulphur. This determines the order of our proportions.

Cu_2S : S = copper present : sulphur required for copper				
4	: 1 =	4.5	:	1.1

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As there is 6 per cent. of sulphur in the ore we subtract the 1.1 required by the copper, leaving 4.9 per cent. of "residual" sulphur to be combined with iron. In the proportion now to be figured for FeS, make this sulphur the third term:

S	: Fe =	residual sulphur	:	iron in matte
32	: 56 =	4.9	:	8.5

There was originally 18 per cent. iron in the ore. Subtract now the iron required for matte formation; 18 − 8.5 = 9.5.

This is, 9.5 per cent. of the iron is left for slag formation.

(*d*) A mineral analyzes as below:

Silica	68.80 per cent.
Iron	5.60 per cent.
Zinc	6.50 per cent.
Copper	6.30 per cent.
Sulphur	12.80 per cent.
Total	100.00 per cent.

Assuming that the elements are present as CuS, FeS_2 and ZnS, respectively, write the analysis by compounds instead of elements.

Fe : S_2 = 56 : 64 = 5.6 : 6.4	FeS_2 =	12.00 per cent.
Zn : S = 65 : 32 = 6.5 : 3.2	ZnS =	9.70 per cent.
Cu : S = 63 : 32 = 6.3 : 3.2	CuS =	9.50 per cent.
	SiO_2 =	68.80 per cent.
Total, by compounds		100.00 per cent.

This is a mere "set up" case, with all the elements exactly satisfied, but the method serves in matte computation, when we must allow for sulphides before figuring our silicates. In this example the summation is complete, but such is very rarely the case in practice. In most raw, and in all roasted sulphide ores there will be an analytical deficit when only the metals, sulphur and silica are accounted for. This deficit stands chiefly for oxygen combined with the metals. A trial on the principle of the above will serve to "adjudicate" the metals to the oxygen deficit, and a summation fairly complete may thus be usually obtained.

(*e*) A zinc ore contains 62 per cent. of zinc, which is present as sulphide, ZnS.

1. What is percentage of ZnS in the ore?

2. What will the ore weigh after roasting, if all the ZnS becomes ZnO?

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3. What will be the assay in zinc, of the product?

Solution.

(1) ZnS contains 67.01 per cent. Zn, and 32.99 per cent. S, so that:

$$67.01 : 100 = 62 : 92.52 = \textit{per cent. ZnS in the ore.}$$

(2) $$\begin{matrix} ZnS : ZnO = ZnS : ZnO \\ 97 : 81 = 92.52 : 77.26 \end{matrix}$$

Then ZnS − ZnO = 92.52 − 77.26 = 15.26 lbs. = loss of weight.

As we are supposed to figure always from the unit figure of 100 lbs., our 100 lbs. will now weigh 100 − 15.26 = *84.74 lbs.*

(3) $$\frac{6200}{84.74} = 73.16 = \textit{percentage of zinc in the roasted ore.}$$

(*f*) This is similar to (*e*) but is, so to speak, "inverted."

A lot of zinc ore is roasted, all the ZnS being converted into ZnO. All the zinc having been present originally, as ZnS, we now find the weight of the roasted lot is 100 lbs., and its assay 70 per cent. of zinc.

It is required to find:

1. From what weight of raw ore was this 100 lbs. of roasted ore produced?

2. What was the zinc assay of the raw ore?

3. What was percentage of zinc oxide in the roasted product?

Solution.—(1) 70 per cent. zinc makes 87.23 zinc oxide, hence there are 12.77 per cent. of impurities (*i.e.*, 12.77 lbs. in the 100 lbs. considered.)

$$ZnO : ZnS = 81 : 97 = 87.23 : 104.46$$

This weight 104.46 is that of the original *ZnS alone.* Add 12.77 we have as original weight of the raw ore *117.23* lbs.

2. Zinc assay of original ore,

$$\frac{70 \times 100}{117.23} = 59.7 \text{ per cent. zinc.}$$

3. This has already been obtained in (1), *i.e.*, 87.23 per cent.

(*g*) A pyritiferous hematite is roasted, having originally contained only SiO_2, Fe_2O_3, and FeS_2. When all of the FeS_2 has become Fe_2O_3, it is found to have lost 4 per cent. of its weight, and assays 64.166 iron.

1. What were original percentages of FeS_2, Fe_2O_3, and SiO_2? Also, give separate original percentages of iron and sulphur.

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2. What are present percentages of Fe_2O_3 and SiO_2?
Solution:

$$2FeS_2 : Fe_2O_3 = 240 : 160$$

That is, the loss in weight equals one-third of the weight of the FeS_2. As this loss was four pounds the ore originally contained 3×4 or 12 lbs. of pyrites (in 100 lbs.).

It contributed 5.6 to per cent. of iron in original, and $\frac{5.60}{0.96}$ = 5.833 to iron in roasted ore, leaving 58.33 as iron in the unchanged Fe_2O_3.

Hence Fe_2O_3 in roasted ore is 91.66 per cent., and SiO_2 is 8.33 per cent.

Analysis of the original ore is as follows:

FeS_2	12.00 per cent.
$Fe_2O_3 = \frac{58.33}{0.7} \times 0.96 =$	80.00 per cent.
$SiO_2 = 8.33 \times 0.96 =$	8.00 per cent.
Total	100.00 per cent.

(*h*) An ore is reported as containing:

SiO_2	23.94 per cent.
Fe	23.80 per cent.
Pb	10.35 per cent.
Zn	9.75 per cent.
S	32.16 per cent.
Total	100.00 per cent.

Recalculate as FeS_2, PbS and ZnS, showing summation for proof.

Fe : S_2 = 56 : 64	= 7 : 8	= 23.8 :	27.2	= S in FeS_2
Pb : S = 207 : 32		= 10.35 :	1.6	= S in PbS
Zn : S = 65 : 32		= 9.75 :	3.36	= S in ZnS
Proof for sulphur			32.16	= total S.

The revised analysis is as follows:

Fe, 23.80 + S_2, 27.2 = FeS_2 =	51.00 per cent.
Pb, 10.35 + S, 1.6 = PbS =	11.95 per cent.
Zn, 9.75 + S, 3.36 = ZnS =	13.11 per cent.
SiO_2	23.94 per cent.
Total summation by compounds	100.00 per cent.

These checks, or similar ones, should never be omitted. The following is a problem hardly "practical" but involving useful methods of computation.

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(*i*) An ore has the following analysis:

SiO_2.... 31.48 per cent.			
FeS_2.... 30.00 per cent.	Fe....14.00	S_2....16.00 per cent.	
PbS.... 19.12 per cent.	Pb....16.56	S .... 2.56 per cent.	
ZnS .... 19.40 per cent.	Zn....13.00	S .... 6.40 per cent.	
100.00 per cent.	Total sulphur.....24.96 per cent.		

This ore is roasted until it contains no more *sulphides*, losing 10 per cent. of its lead and 20 per cent. of its zinc in fumes.

All of the iron has now become Fe_2O_3.

$\frac{1}{2}$ of the remaining lead goes to PbO and $\frac{1}{2}$ to $PbSO_4$. $\frac{1}{3}$ of the remaining zinc goes to ZnO and $\frac{2}{3}$ to $ZnSO_4$.

1. What is weight of the roasted product?
2. What is summation analysis of same?

This may be done in several ways, all involving the same method in point of fact. As easy a way as any is to open a debit and credit account, setting losses against gains according to the specified conditions. Gains are all in oxygen.

We here tabulate the whole, distinguishing between O in oxides and in sulphates:

Losses.	Lbs.	Gains.	Lbs.
FeS_2 loses S_2	16.000	O	6.00
PbS loses 1/10 of Pb	1.656	O (in PbO)	.576
PbS loses 1/10 of S	.256	O_4 (in $PbSO_4$)	2.304
PbS loses 1/2 of 9/10 S	1.152	....	....
ZnS loses 2/10 of Zn	2.600	O (in ZnO)	.853
ZnS loses 2/10 of S	1.280	O_4 (in $ZnSO_4$)	6.826
ZnS loses 1/3 of 8/10 S	1.706	....	....
Total loss	24.650	Total gain	16.559
Subtract	16.559		
Net loss	8.091		

Composition by weights of roasted product.	Lbs.	Summation analysis of same.	
SiO_2	31.480	SiO_2	34.251 per cent.
Fe	14.00	Fe	15.232 per cent.
O (in Fe_2O_3)	6.00	Pb	16.216 per cent.
Pb	14.904	Zn	11.316 per cent.
O + O_4 (with Pb)	2.880	S	4.968 per cent.
S in SO_4	1.152	O	18.016 per cent.
Zn	10.400		99.999 per cent.
O + O_4 (with Zn)	7.679		
S in SO_4	3.414		
	91.909		

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Original weight 100 lbs., present weight 100 − 8.091 = 91.909 lbs.

Summation analysis by compounds:

SiO_2	34.251 per cent.
Fe_2O_3	21.760 per cent.
PbO	8.735 per cent.
$PbSO_4$	11.868 per cent.
ZnO	4.701 per cent.
$ZnSO_4$	18.670 per cent.
	99.985 per cent.

The procedure in such computations having been sufficiently indicated, the actual proportions and computations are omitted. They are somewhat tedious, but absolutely simple in principle.

In reducing any product or mixture, whose various constituents are known by weight, to the form of a summation analysis (100.00 per cent.), we may either, as already shown, divide each weight multiplied by 100 by total weight, or else may find a factor by which to multiply each separate weight. Having adopted one of these methods, adhere to it.

(*j*) A calculated matte should contain:

FeS	65 lbs.
Cu_2S	10 lbs.
PbS	7 lbs.
ZnS	5 lbs.
	87 lbs.

We may write, $\frac{6500}{87} = 74.71$ and so on for the other constituents, or else divide 100 by 87, getting quotient of 1.149 and using this as multiplier on each substance, get substantially the same result, *e.g.:*

$$65 \times 1.149 = 74.69 \text{ per cent. FeS}$$

and similarly for all others.

Details so trivial as this appear at first sight to be superfluous. But nothing is superfluous which tends to minimize chances of error on the part of a tired computer, and uniformity of method is one of the best guarantees of average correctness.

(*k*) An iron ore has 88 per cent. Fe_2O_3, and 0.8 phosphoric anhydride (P_2O_5). In smelting it produces, with its fluxing material:

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1. Pig metal whose analysis shows:

Carbon	3.0 per cent.
Silicon	2.8 per cent.

It also contains *all of the phosphorus*, reduced from the P_2O_5 of the ore.

2. Slag, whose weight is one-fifth of the weight of the ore charge, and which contains 3 per cent. of iron oxide (FeO) derived from the ore.

What weight of the ore produces 100 lbs. of the pig metal?

What is the completed analysis of the pig metal?

No operations are given nor even indicated; the student should be able to select methods for solution.

Answer. Weight of ore which produces 100 lbs. pig = 153.2 lbs.

Analysis of the pig metal:

Iron	93.66 per cent.
Carbon	3.00 per cent.
Silicon	2.80 per cent.
Phosphorus	0.54 per cent.
Total	100.00 per cent.

Examples enough have been given to enable the student to easily follow the cases now to be introduced of actual furnace calculation.

As an example of calculation by "excess," we take a case from the actual record of an iron blast furnace.

Very rarely is any flux employed in the iron furnace except limestone, though this may be either a limestone proper or a magnesian lime. There is some prejudice against magnesia, as it has been supposed to "stiffen" the slag. This hardly applies to the iron furnace, as excellent and free flowing slags have been often produced with a considerable percentage of magnesia in their composition.

It is, however, not possible to run an iron furnace on silicate of lime. No lime silicate is fusible enough to act as a slag. The almost universal presence of alumina in iron ores makes it possible to produce slags of sufficient fusibility to run freely and separate from the pig metal.

It occasionally happens that the charge is too exclusively silica and lime, in which case the furnace produces a slag with

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iron in it. This is a serious matter, as iron in a slag should always be under 1 per cent. Chemical laws come in, in spite of the reducing action. The "demand," so to speak, of the silica for a fusible slag produces a double iron-lime silicate.

The charging of too little limestone produces the same effect. This was a common happening in old-fashioned practice, the fallacy that "the less you put into the furnace the less work she has to do" led to lime charges that were too small for the silica, the consequence being that iron was drawn into the slag.

The general fact seems to be that di-basic or poly-basic slags are more tractable than slags with a single base. Thus if a silicate of alumina be prepared by mixture of ingredients, also a silicate of lime, and the fusion be separately attempted, the results will be mere "frits" at any reasonable temperatures. But if these very mixtures be now joined, the resulting double lime-alumina silicate proves to be fairly fusible. Numerous experiments have proved the general law of the greater fusibility of polybasic silicates.

As for magnesia, in the iron furnace, the writer knows a case where the limestone was so magnesian that it might have been called a dolomite, yet the slag was excellent. Some alumina was always present, however, and evidence as to action of a purely lime-magnesia base is lacking.

The slag given is about the average of a number of months, and was, except when the furnace was "in trouble," very nearly white, clean and free flowing. As here calculated it is of course theoretical, but is very close indeed to the actual record of the furnace.

Materials.	Iron ore.	Limestone.	Coke.
Silica	8.00	6.00	8.00 per cent.
Fe_2O_3	87.00	....	.... per cent.
Al_2O_3	5.00	....	.... per cent.
MgO	....	6.00	.... per cent.
CaO	....	46.00	.... per cent.

Assume 100 pounds of ore as basis for calculation. Find weight of limestone necessary to form a "singulo" silicate.

In computing charges for the iron furnace it is important to figure on the mineral constituents of the coke, owing to the large ratio of fuel employed.

To simplify the present calculation the ash of the coke is

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stated as composed of silica only, though in reality it contained a small percentage of bases.

A certain amount of silica always enters the metal as silicon, and some allowance should be made for this fact. This is arbitrary, as the amount varies with fuel ratio and running of the furnace. The subtraction of *three per cent.* from the silica of the ore is a fair allowance, although it would often be too low. However, this subtraction will always make for better, *i.e.*, closer figures on slag than its neglect.

Hence we figure in the present instance on *5 per cent. of silica instead of 8 per cent.* This affects only the silica of the ore, leaving the silica of the limestone and of the coke as in the analysis.

The "singulo" formulæ are: $2Al_2O_3,3SiO_2$; $2CaO,SiO_2$; and $2MgO,SiO_2$.

Under the conditions, and the selection of material, no set ratio *between bases* is possible. As we have taken 100 lbs. of ore the figures will indicate either "pounds" or "percentages."

Fuel (coke), seventy per cent. of the weight of the ore.

This being a first case we figure it out in great detail, dividing the statement into four headings.

(1) Take out alumina silicate from the ore. That is, ascertain what per cent. of silica is demanded by the 5 per cent. alumina. Use the formulæ in all of these proportions, and *nearest whole numbers* from table of atomic weights. Balling's tables could also be used.

$$2Al_2O_3 : 3SiO_2 = 204 : 180 \ (= 17 : 15) = 5 : 4.412$$

Pounds silica required by alumina, 4.412. Sum up all the silica of ore and coke and subtract this requirement from the total.

Silica in ore (8 − 3).....	5	pounds (or five per cent.)
Silica in coke.....	5.6	pounds (*i.e.*, 8 p.c. of 70)
Silica total, ore + coke.....	10.600	
Less required by alumina.....	4.412	
SiO_2 available for limestone...	6.188	(6.188 pounds per 100.)

(2) The limestone has now to be "prepared" (by calculation) for adjustment to the ore, etc. That is, the silica must be adjusted to its proper ratio of bases in the limestone itself. It is only the excess of lime *above* this silica requirement which can

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be called "available" for the silica of ore and coke. We have 6 per cent. magnesia in the limestone, formula as above:

$$2MgO : SiO_2 = 80 : 60 \ (= 4 : 3) = 6 : 4.5$$

Six is actual magnesia, 4.5 is its *required* silica, in terms (percentage) of limestone. However, as there is *6 per cent. silica in the limestone*, we now subtract this 4.5 and there remains 1.5 per cent. which must be taken care of by lime. (In order to bring lime into last term, put SiO_2 first.)

$$SiO_2 : 2CaO = 60 : 112 \ (= 15 : 28) = 1.5 : 2.8$$

A little later we shall show how lime and magnesia might have been figured at one operation by means of a "conversion factor."

(Let the student note that if it had happened that there was *not enough* silica in the limestone to satisfy the magnesia, then the magnesia would have taken the "unknown" term, and when the per cent. of magnesia had been found which satisfied all of the silica, the remainder ("residual") magnesia would have gone in with the available lime.)

We have found 2.8 lime is required by the last 1.5 of the silica in the limestone. Subtract this, therefore, from the total lime.

$46 - 2.8 = 43.2$. That is, in our limestone we have *43.2 per cent. of "available" lime* (CaO) for combination with "outside" silica.

(3) Now we bring together the ore and the limestone, with their respective excesses, viz: SiO_2 excess in the ore and CaO excess in the limestone. The question is: "What amount of lime is called for by the silica excess of the ore?" Since we are figuring on 100 lbs. of ore and seeking the required lbs. of limestone, we naturally put the silica excess first in our proportion.

$$SiO_2 : 2CaO = 60 : 112 = 6.188 : 11.551$$

The lime called for (CaO) by 100 lbs. of ore is therefore *11.551 lbs.* But this must be "available," *i.e.*, free lime, and we have just found that our limestone yields *43.2 per cent.* of this. Hence the evident proportion:

$$43.2 : 100 = 11.551 : 26.738$$

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Therefore 100 lbs. ore require *26.738 lbs. limestone.*

We have carried the decimals beyond any practical necessity.

It remains only to "assemble" our figures and check up. The analysis of the slag may then be figured.

(4) Take 100 lbs. of the ore, 70 of coke and 26.738 of limestone, and figure out *actual lbs.* of each and every constituent. This will give total weight of the slag, and enable us to figure analysis of the latter in percentages.

	SiO_2.	Al_2O_3.	CaO.	MgO.
In ore	*5.00	*5.00	....	....
In limestone	†1.604	....	‡12.30	†1.604
In coke	§5.60	....	....	....
Totals	12.204	5.00	12.30	1.604

Weight of the slag per 100 lbs. of ore charged = 31.108 lbs. Analysis as below, by rule III (*c*):

Silica	39.23 per cent.
Alumina	16.07 per cent.
Lime (CaO)	39.54 per cent.
Magnesia (MgO)	5.15 per cent.
Total	99.99 per cent.

This is a fairly proportioned slag for the iron furnace, with silica rather higher than in average modern practice. As lime is beneficial in keeping sulphur out of the metal, it is probable that if the ore were sulphurous the "lime burden" would be increased a little.

Owing to the high temperatures of the iron furnace, it is not necessary to obtain slags fusible at comparatively low figures. Hence a wide margin in silica percentage is permissible.

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* 5 per cent. of 100 lbs. † 6 per cent. of 26.738 lbs.
‡ 46 per cent. of 26.738 lbs. § 8 per cent. of 70 lbs.

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SIMPLIFICATION OF DATA PREVIOUS TO CALCULATION.

In ores of lead, copper and the precious metals we frequently have a large number of elements, some of which will be reckoned as completely reduced to metal (*e.g.*, lead and its accompanying gold and silver), some brought into the form of matte with sulphur or of speiss with arsenic, others leave the furnace as slag (silicates), while finally an uncertain proportion will be dissipated in fumes, either permanently lost or partly regained as "flue dust."

Usually the latter losses are uncalculated, but when stock and all other conditions are fairly constant, it becomes possible in the light of experience to make close allowances for these "subtractive" elements of computation.

If for example in smelting an ore high in zinc, analysis of products shows one-fifth of same unaccounted for, such a loss would become part of the data.

Such allowances consist merely in omission of the presumed losses from the weights or percentages as shown by the analysis.

As it may be a matter of complexity to make separate figures for each and every base, it is a common practice to substitute one for another, *e.g.*, when lime and magnesia are both present, calculate all as lime. This is sometimes done "weight for weight," more usually according to the chemical relations of the bases, that is, in stoichiometric ratio.*

Manganese and iron are so close in atomic weight that it is usual to add manganese to the iron weight in calculation, without change.

At best, there is much that is conventional in this substitution. It is sometimes inevitable. Naturally the metallurgist will try to group together bases which may be presumed to act similarly toward silica or toward the other bases in the slag. For the assumption underlying the substitution of one element

* When the totals of the bases thus treated are small, we may disregard chemical ratios, and lump them "weight for weight," under one head.

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for another must be that the displacing element will act in a manner similar to the one displaced.*

No one supposes anything of the kind, the whole simplification by this artifice being a convention for the reduction of slags to certain "type" forms. All that can be done is to see to it that too great violence is not done to the facts as demonstrated by long experience.

"As nearly as I can make it out," remarked a metallurgist of very great practice to the writer, "the rule is to call manganese, *iron;* and everything else, *lime.*" This, while a humorous exaggeration, is fairly close to the actual practice in a large class of working problems.

Take a single example. We have zinc to treat as slagging material, and we place it in the lime group by multiplying by 0.7. The result will be that in computing for the addition of limestone as flux, we shall use less of it, as we have already a "conventional" lime in the shape of the calculated zinc. Here is a case where we make this substitution on the principle "by contraries." The more lime in a slag the worse is its carrying power for zinc oxide; in fact, there comes a point where the slag, getting too high in lime, refuses to accept zinc at all, throwing it into crusts and fumes to the damage of good running. Thus, the figuring of zinc into the lime column is far from indicating that these two act similarly, but it serves a purpose, nevertheless, by diminishing the *actual* lime. (CaO = 56. ZnO = 81. These are very nearly as 7 to 10.) Other substitutions, however, are in accord with chemical similarity.

Take a simple illustration of this substitution. We have a limestone whose analysis shows CaO 39 per cent., MgO 9 per cent. Now, since

$$MgO : CaO = 40 : 56 = 1 : 1.4$$

we can, if we have occasion to reduce the number of our bases for computation, figure thus: MgO $\times$ 1.4, that is, 9 $\times$ 1.4, is equivalent to 12.6 CaO. Then we add this to the actual lime: 39 + 12.6 = 51.6.

The excess figured from analysis will not be affected by this sub-

* For example, we combine *actual* lime and *actual* magnesia into one weight, which we calculate thenceforth as lime. These two are the "displacing" and "displaced" bases, *in the computation.*

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stitution. An example will make this clear. Take the above limestone; suppose it to contain, in addition to the bases as given, 10 per cent. silica.

We are figuring on the basis of a "singulo" silicate, and want to know the basic excess of the limestone. First take it as it stands, *i.e.*, without the transformation of the MgO.

$2MgO : SiO_2 = 80 : 60 = 4 : 3 = 9 : 6.75$ SiO_2 required for MgO
Total $SiO_2 = 10$. $10 - 6.75 = 3.25 = SiO_2$ remaining for lime
$SiO_2 : 2CaO = 60 : 112 = 3.25 : 6.07$ CaO

Total lime, less that required by $SiO_2 = 39 - 6.07 = 32.93$

Now make the change of MgO into CaO by using factor as above, we get total lime = 51.6. Figure CaO excess in regular way:

$SiO_2 : CaO = 60 : 112 = 10 : 18.67 = CaO$ required by SiO_2
$51.60 - 18.67 = 32.93$

or exactly the former figure.

This is *a priori* evident to anyone to whom the stoichiometric relation has become familiar. We again remind the practitioner that we are here, as in many other places, writing for the student.

An example in "simplification" will now be given.

A carbonate ore analyzes as follows:

SiO_2	36.3 per cent.
FeO	16.0 per cent.
MnO	5.9 per cent.
CaO	5.6 per cent.
MgO	4.0 per cent.
S	5.1 per cent.
As	0.6 per cent.
Pb	18.0 per cent.
Cu	4.4 per cent.
CO_2 and O	4.1 per cent.
Total	100.0 per cent.

(1) Adjust matte and speiss.

$Cu_2 : S = 4 : 1 = 4.4 : 1.1 = S$ for Cu_2S in matte.

(2) S remaining is 5.1 − 1.1 or 4 per cent. Take out FeS to the extent that this S permits.

$S : FeO = 32 : 72 = 4 : 9$

= per cent. of FeO to be subtracted. This leaves (16 − 9) 7 per cent. FeO.

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(3) Take out As and Fe, as Fe_5As.

$$As : 5FeO = 75 : 360 (= 5 : 24) = 0.6 : 2.88$$

FeO finally remaining for slag is $7 - 2.88 = 4.12$.

NOTE.—It is quite useless, if the analysis states the iron as FeO, to reduce this to Fe (metallic iron) in calculating out S and As. Take the equivalent amounts (molecular weights) of the compounds given by the analysis. As this may not be at once evident to the student, we here step aside to "take out" the As in the ordinary way, viz. (look at "3" above):

$$As : Fe_5 = 75 : 280 = 0.6 : 2.24$$

That is, metallic iron required is 2.24 per cent. But now we would have to convert this into FeO, in order to subtract, thus:

$$Fe : FeO = 56 : 72 = 2.24 : 2.88$$

precisely the figure obtained before by one proportion instead of two.

This is very elementary; but it is by no means uncommon to see just this "'round the corner" way of calculating, through lack of familiarity with the language of symbols.

To resume the calculation:

(4) Reduce the bases to two groups. Let us suppose that the required slag is to have a certain ratio of FeO to CaO. As we have four slagging bases we reduce MnO to FeO, and MgO to CaO.

As the molecular weights of FeO and MnO are as 72 : 71 it is the universal practice to combine them by simple addition. So we merely add residual iron to all of the manganese oxide, $4.12 + 5.9$, and call this the total available FeO = 10.02, which might as well be entered as 10 per cent. for all the practical difference it would make.

Also, $MgO \times 1.4 = 5.6$ nominal lime, CaO.

Total CaO will figure as $5.6 + 5.6$ or 11.2 per cent.

Thus we have prepared the ore for calculation, so to speak. Whatever fluxes are to be used can now be computed.

The copper, sulphur and arsenic are disposed of.

The iron has been accounted for to the extent rendered necessary by the residual sulphur and the arsenic. The lead is out of the calculation, under the supposition of its complete reduction.

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The silica and the fluxing bases are arranged, albeit in part conventionally, for adjudication with one another and with their proper weights of other flux.

Remains then, for calculation:

Silica	36.3
Iron oxide	10.0
Lime (CaO)	11.2
Total	57.5 lbs.

for actual slag reckoning.

But these are not actual pounds, that is, not altogether, as the 4 of magnesia have become 5.6 of nominal lime. These and the pounds of FeO are the *chemical equivalents of pounds* in the special relation into which they are now to be brought with fluxing material.

Let us assume that we have a hematite for iron flux, containing SiO_2, 4 per cent., and FeO, 86 per cent. (The analysis would, of course, show Fe_2O_3, but this is reduced by the ratio 10 : 9 to FeO.)

We may figure the whole charge on the basis of percentage alone as we have so far. That is, assuming 100 lbs. as ore charge, pounds and "per cents." become the same expression in numbers.

Find what weight of this flux must be used to produce a bisilicate slag with the ore. It is hardly necessary to go into the details of this calculation, as it has been twice made in previous examples. We outline it, and the student should verify the results. (Bisilicate form, CaO, SiO_2.)

SiO_2 taken from the ore by its CaO	12.00 per cent.
SiO_2 taken from the ore by its FeO	8.33 per cent.
	20.33 per cent.

SiO_2 left for bases in the iron flux = 15.97 per cent. of the ore.

In the iron flux: FeO required by its own SiO_2 = 4.8 per cent. This leaves 81.2 excess of FeO for "available." The final adjudication gives:

SiO_2 : FeO = 5 : 6 = 15.97 : 19.16 = FeO required by SiO_2 of the ore.
81.2 : 100 = 19.16 : 23.6 = weight required in lbs. of the iron flux.

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The slag (leaving out of account the difference in weight caused by substitution of 5.6 nominal CaO for 4 lbs. actual MgO), figures out as follows:

SiO_2 from ore	36.30	
SiO_2 from iron flux	0.94	37.24 lbs.
FeO from ore	10.00	
FeO from iron flux	20.30	30.30 lbs.
CaO from ore		11.20 lbs.
		78.74 lbs.

Analysis of slag:

SiO_2	47.3	per cent.
FeO	38.5	per cent.
CaO	14.2	per cent.
	100.00	per cent.

The student may verify by simple calculations.

In strictly formulistic slag calculations, it is not often necessary to transform one base into another, after the fashion shown above, where it was used merely as an exercise.

In most cases of computation for given percentages, however, these transformations are made, since calculations for percentage, rather than chemical ratios, have become the rule. Certain proportions are considered as "types," *e.g.:*

SiO_2	40.00	per cent.
FeO(MnO)	34.00	per cent.
Ca(Mg, Ba,)O	26.00	per cent.
	100.00	per cent.

This being assumed, the various bases are transformed by their proper factors into one or the other of the "groups" and the calculation proceeds.

Conversion Factors for Bases.

Iron and Manganese.—These metals have for atomic weights 56 and 55, respectively, and for protoxides 72 and 71. Hence it is hardly worth while to adopt any factor. The percentage of manganese oxide is added to that of iron oxide, and the whole is treated as iron oxide.

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Alumina.—This is supposed to act as an "acid" and to form "aluminates" with strong bases, just as silica forms silicates. In slags high in silica, alumina certainly acts as a base, and is so calculated. In iron smelting it is highly probably that in slags low in silica and containing considerable amounts of both alumina and magnesia, a compound of these is formed of a highly infusible nature, possibly something like spinel, whose formula is MgO,Al_2O_3. Alumina 71.8 per cent. and magnesia 28.2 per cent.

Opinions differ as to how to "group" alumina, and some metallurgists are inclined to dodge the question, when its proportion is not great, by setting it apart with an apportionment, it may be, of silica, to take care of it, but letting it be a thing aside from the nominal "formula" or "type" of the slag.

Taking any of the ordinary relations, say bisilicate, and compare alumina with lime silicate by equalizing the silica, we have: Al_2O_3, $3SiO_2$ and $(CaO)_3$, $3SiO_2$. That is, in relation to saturating power for silica, since $Al_2O_3 = 102$ and $3CaO = 168$, we should have 1.65 as factor for converting alumina to lime.

Magnesia.—Multiply MgO by 1.4 as already shown, for CaO.

Baryta.—BaO : CaO = 153 : 56. This gives 0.366, but the factor used is 0.4. The matter is so far conventional that it is not worth while to split hairs or second decimals over it.

Zinc.—Zinc oxide = 81; CaO = 56. $81 \times .7$ is close enough to .56 for us to safely adopt 0.7 as factor for conversion of zinc oxide into CaO.

Zinc oxide and baryta are "undesirable citizens" in any slag, as both are somewhat uncertain in their actions. Some of the features of zinc have already been noted. Baryta divides largely according to the heat and reducing action of the furnace, some of it often goes into barium sulphide, and this in turn joins itself to matte rather than slag.

Iron confers fluidity on almost any mixture. Since in the matting furnace the two essentials for good separation of slag and matte are (1) fluidity, and (2) sufficient difference in specific gravity, it becomes a difficult question at times, whether the additional specific gravity given to a slag by heavy percentage of iron is counterbalanced by the extra fluidity obtained.

Lime per contra may be taken as almost the opposite in these considerations, since it certainly diminishes the specific gravity,

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as compared with a slag of greater iron per cent., but high lime slags are objectionable as a rule, and the iron would be preferred. In fact we see very few analyses of slags higher in lime that in iron oxide, and the conditions under which they become inevitable are rare.

These remarks have no bearing on iron metallurgy. At the great majority of iron furnaces slags high in lime are the rule, and lime, magnesia and alumina are the only bases, except by accident, or in the case of manganiferous ores. But the temperatures in an iron "stack" take it out of the range of the heat and reduction power of the lead or copper-matting furnace.

Notwithstanding the utility of these "conversions" it is no uncommon practice to omit them entirely. When to do so is a question of detail belonging rather to the requirements of special cases than to a general treatise.

Example.—A slag problem is often put into something like the following form.

Required.—A slag whose composition shall be:

Silica	35.00 per cent.
Iron oxide	45.00 per cent.
"Earthy bases"	20.00 per cent.
	100.00 per cent.

It will shortly be seen that our "representative" method, which deals directly only with cases in which percentages are the requirement, is simplified, not complicated, by such a wholesale bunching of bases.

It is obvious that if we have merely to add together the percentages (or weights, as the case may be) of the "earthy bases," without regard to any chemical consideration, we have simplified the calculation. Whether we have simplified the running of the furnace is quite another question.

Although we shall give a case or two involving the lumping of all bases except iron oxide, in an "arithmetical" sense, *i.e.*, taking no account of the differences in their saturating power for silica, it forms no real addition to any "method" to illustrate this procedure. The difference is one of omission. Instead of "adjudicating" according to chemical "weights" we adjust nothing, but add together all the bases specified.

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Problem of mixing ores.—It is sometimes necessary to mix ores or other material, so that the mixture shall contain a certain percentage of a given substance. The problem is indeterminate unless there are but *two* lots to be mixed.

The problem is readily formulated. It can then be "translated" into the following rule, viz.:

Take weights of the ores in inverse ratio to the differences between their assays and the (required) assay of the mixture.

Example.—(*a*) Mix two ores containing respectively 40 per cent. and 8 per cent. of a certain constituent, so that the mixture shall contain 16 per cent.

No. 1. The larger per cent. less the required per cent. is $40 - 16 = 24$.

No. 2. The required less the smaller per cent. is $16 - 8 = 8$.

Now take weights of the two ores *inversely* as these figures, *i.e.*, take 8 parts of No. 1, and 24 parts of No. 2 (or, in this case, reducing to simple ratio, 1 part of No. 1 and 3 parts of No. 2).

Proof.

100 lbs. of No. 1 contain.....	40 lbs. metal
300 lbs. of No. 2 contain (3×8).....	24 lbs. metal
400 lbs. of mix contains.....	64 lbs. metal

$$\frac{6400}{400} = 16 \text{ per cent., as required.}$$

If we have three lots there is no definite solution. The intermediate or required figure falls either between No. 1 and No. 2 or between No. 2 and No. 3, so that in any case we have a definite solution for only two ores, those, namely, between whose percentages the required percentage falls.

We may, however, by limiting the weights of one lot to a certain figure or by stipulating a certain proportion *as between certain classes of ore*, reduce the problem to a determinate one.

Although cases of this kind are exceptional, it is well to have a ready method of figuring on them.

(*b*) We have three ores, whose assay is 39, 24 and 8 respectively. (N. B.—It makes no difference whether the figures indicate percentages or ounces to the ton.) We want 16 per cent. in mixture. This may obviously be obtained from 1 and 3 or from 2 and 3. But we are compelled to use *both* 1 and 2 and the latter in twice the quantity of the first. What proportions of the three ores in the mixture?

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100 lbs. of 1 contain.....	39 lbs. of substance
200 lbs. of 2 contain.....	48 lbs. of substance
300 lbs. of mix contain.....	87 lbs. of substance

The "mix" then contains

$$\frac{87 \times 100}{300} = 29 \text{ per cent.}$$

Now proceed as in (*a*), calculating on the mix as an ore to be used in getting second mix.

$$29 - 16 = 13, \text{ and } 16 - 8 = 8$$

Take, then, 8 units of the mix and 13 units of the No. 3 ore.

Suppose we also have to make up an "even" weight of the total mixture. We divide the required weight into 21 parts (8 + 13) and take 8 and 13 of these parts respectively. Or we may go back to original ore parts. In the present case in 1000 lbs. mix we would have 127, 254 and 619 lbs. of 1, 2 and 3 respectively. Prove this as in former example:

$$\left.\begin{aligned} 127 \times .39 &= 49.53 \\ 254 \times .24 &= 60.96 \\ 619 \times .08 &= 49.52 \end{aligned}\right\} \text{Sum} = 160 = 16 \text{ per cent. of } 1000$$

Concentration.—Ordinarily the furnace treating concentrates buys them from the mining or milling company, and has little or nothing to do with the question of concentration. A check on operations of this nature is appended. It has to do with the simplest case only, *i.e.*, the one where the only products are concentrates for treatment, and "tailings."

The formula may be extended to meet any case, one for example in which there are two distinct "products," and tailings.

The data by which to check are: (1) assay of the crude ore; (2) assay of concentrates; (3) assay of tailings, and (4) ratio of concentrates to total.

If this ratio be called "*R*" and the assays of ore, concentrate and tailings be respectively *a*, *b* and *c*, then designating the weight of ore by unity, we evidently have: $bR + c(1 - R) = a$; that is, metal in concentrates plus metal in tailings equals metal in original total ore.

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This gives by solving with respect to R:

$$R = \frac{a - c}{b - c}$$

We may solve with respect to any other letter.

$$a = R(b - c) + c \qquad b = \frac{Rc + a - c}{R} \qquad c = \frac{Rb - a}{R - 1}$$

Examples:

1.	$R = 0.25$	$a = 15$	$b = 40$	$c = 6.66$
2.	$R = 0.15$	$a = 22$	$b = 80$	$c = 11.76+$
3.	$R = 0.05$	$a = 10$	$b = 195$	$c = 0.26$
4.	$R = 0.2$	$a = 12$	$b = 48$	$c = 3.0$
5.	$R = 0.1$	$a = 16$	$b = 151$	$c = 1.0$
6.	$R = 0.2$	$a = 15$	$b = 67$	$c = 2.0$
7.	$R = 0.01$	$a = 20$	$b = 1950.5$	$c = 0.5$
8.	$R = 0.166$	$a = 22$	$b = 120$	$c = 2.4$
9.	$R = 0.15$	$a = 6.95$	$b = 35$	$c = 2.0$

Three of these being known the fourth may be calculated. Very few custom mills check up their work carefully enough to know exactly what they are doing. The application of this little proof, simple as it is, would perhaps surprise some of those who are so positive in their claims of "ninety per cent. saving."

To determine the percentage recovered in concentration, without assay of the tailings:

"Divide assay of concentrates by the ratio of concentration, multiply the product by 100, and divide by assay of original ore." In this rule the "ratio" is the "number of tons into one."

Example.—Take *Example 1* above. It shows "four into one" as ratio.

$$\frac{40}{4} = 10. \quad 10 \times 100 = 1000$$

$$\frac{1000}{15} = 66.67 \text{ or } \frac{2}{3} \text{ recovery}$$

This is easily verified, for assay of original ore being 15 oz., four tons yield 60 oz., two-thirds of which = 40.

Take No. 3: $R = 0.05$ indicates 20 into 1. Then:

$$\frac{195}{20} = 9.75$$

$$9.75 \times 100 = 975. \quad \frac{975}{10} = 97.5$$

Recovery = 97.5 per cent.

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The method is too simple to be worth further exemplification.

A few tables are appended, which explain themselves. The first one, showing the proportions of silica and base in various silicates, is mainly taken from Balling. Analyses of most of these are added, which is the same thing in another form. For applicate utility the first is better suited. To the Balling table, Hofman (Metallurgy of Lead) adds BaO and PbO.

PROPORTIONAL TABLE FOR SILICATES.

For Singulo-Silicates: 1 part by weight of silica requires:	Parts by weight of bases.	*For Singulo-Silicates:* 1 part by weight of bases requires:	Parts by weight of silica.
Lime (CaO)	1.86	Lime	0.535
Baryta (BaO)	5.10	Baryta	0.196
Magnesia (MgO)	1.33	Magnesia	0.750
Alumina (Al_2O_3)	1.14	Alumina	0.873
Ferrous oxide (FeO)	2.40	Ferrous oxide	0.416
Manganous oxide (MnO)	2.36	Manganous oxide	0.422
Lead oxide (PbO)	7.43	Lead oxide	0.134
For Bi-Silicates:		*For Bi-Silicates:*	
Lime	0.93	Lime	1.070
Baryta	2.55	Baryta	0.392
Magnesia	0.66	Magnesia	1.500
Alumina	0.57	Alumina	1.747
Ferrous oxide	1.20	Ferrous oxide	0.833
Manganous oxide	1.18	Manganous oxide	0.845
Lead oxide	3.71	Lead oxide	0.269
For Sesqui-Silicates:		*For Sesqui-Silicates:*	
Lime	1.24	Lime	0.803
Baryta	3.40	Baryta	0.294
Magnesia	0.88	Magnesia	1.125
Alumina	0.76	Alumina	1.310
Ferrous oxide	1.60	Ferrous oxide	0.625
Manganous oxide	1.57	Manganous oxide	0.633
Lead oxide	4.95	Lead oxide	0.202

PERCENTAGE TABLES, SINGULO AND BI-SILICATES.

SINGULO SILICATES:		*p. c.*	*p. c.*
$2K_2O, SiO_2$	Potassium oxide	75.73	Silica 24.27
$2Na_2O, SiO_2$	Sodium oxide	67.25	Silica 32.75
$2CaO, SiO_2$	Calcium oxide	64.97	Silica 35.03
$2MgO, SiO_2$	Magnesium oxide	57.16	Silica 42.84
$2BaO, SiO_2$	Barium oxide	83.61	Silica 16.39
$2Al_2O_3, 3SiO_2$	Alumina	52.96	Silica 47.04
$2FeO, SiO_2$	Ferrous oxide	70.45	Silica 29.55
$2MnO, SiO_2$	Manganous oxide	70.16	Silica 29.84
$2PbO, SiO_2$	Lead oxide	88.14	Silica 11.86

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BI-SILICATES.

		p. c.	p. c.
K_2O, SiO_2	Potassium oxide	60.93	Silica 39.07
Na_2O, SiO_2	Sodium oxide	50.65	Silica 49.35
CaO, SiO_2	Calcium oxide	48.11	Silica 51.89
MgO, SiO_2	Magnesium oxide	40.00	Silica 60.00
BaO, SiO_2	Barium oxide	71.83	Silica 28 17
$Al_2O_3, 3SiO_2$	Alumina	36.02	Silica 63.98
FeO, SiO_2	Ferrous oxide	54.38	Silica 45.62
MnO, SiO_2	Manganous oxide	54.03	Silica 45.97
PbO, SiO_2	Lead oxide	78.80	Silica 21.20

FORMULISTIC AND "PERCENTAGE" SLAGS.

Although the application of the "excess" is often inevitable, and, in fact, can never be dispensed with in the calculated elimination of mattes, yet there are many cases in which the simplest method for adjustment is to use one or more equations of the first degree. We shall call these "representative" equations, as they are strict representations of the analyses of material.

It will often be a matter of judgment with the computer whether to proceed altogether by the "excess" figures on the plan already indicated, or to "equate" his data. Certain persons imagine that any calculation "with an 'x' in it" is harder than a "merely arithmetical" problem. Before we are through with the subject we shall present examples well fitted to disabuse the mind of such a prejudice. Our "x" problems are indeed the easiest ones we give.

In the adjustment of several materials, all of which enter into the charge, the excess method becomes more and more troublesome, and there are situations in which it is inapplicable, except under modifications themselves complicated. It will not be necessary to consider such examples, since the equation method will easily solve them.

Slags to be calculated by the method of equations may be formulistic or numerical. That is, the requirement may be that a fixed chemical formula shall be maintained, or it may be merely that certain elements must be present in certain proportions or percentages. Frequently the latter requirement has been originally based upon a formula.

As has been shown, any formula may be easily thrown into an analytical form, *i.e.*, expressed as a summation to 100. This

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may not be necessary for calculation, but it is usually done, if only to enable the operator to see at a glance how the analysis compares with well-known types.

As for formulated slags, observe that the mere fact that a slag analyses as a "singulo" or a "bisilicate" does not make it a full chemical "formula." It would, indeed, *were but there one base present.*

Suppose we have a slag carrying iron oxide and lime as its only bases. Let the silica also be so adjusted that its ratio to the iron is FeO,SiO_2, and to the lime CaO,SiO_2. That is a "bisilicate," but the whole is not a chemical formula unless the iron and the lime stand in some simple ratio to each other.

If we write this slag as:

$$FeO,SiO_2 + CaO,SiO_2; \text{ or, } FeSiO_3 + CaSiO_3$$

we enforce upon it the chemical condition implied by the laws of chemical symbolization. The SiO_2 combined with the iron is equal in weight to the SiO_2 combined with the CaO. The FeO weight is to the CaO weight as 72 to 56, or as 9 to 7. This, then, is a truly "formulistic" slag, so called because it can be read and "translated" into exact numerical equivalents without further explanation. It is, in short, a true chemical compound.

The chemical relation of iron oxide to lime here (FeO to CaO) is 1 to 1, *i.e.*, one molecule of each. Their arithmetical relation is whatever is imposed by the relative weights of these particular molecules. We are writing for those whose chemistry has become very rusty. Those who never had any chemical instruction should stop reading here, and book up in the first elements.

Let us now take a singulo silicate *not* a chemical formula, to make the difference clear to the beginner.

Suppose that we have a singulo silicate, the weights of whose iron oxide and lime stand to each other as 17 to 19. We cannot well express that fact in any chemical formula. The expression $17FeO,SiO_2 + 19CaO,SiO_2$ is very far off, being erroneous both as to bases and silica. In fact, when we try to mix chemical formulæ and ordinary weight relations, we had better drop the attempt at once and write out in descriptive phrase what the proportions are by weight, for fear of misapprehension. Many technical articles of recent date "mix things" shamefully in this respect, leaving the reader in final

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doubt as to whether their formulæ are to be read in the only possible correct way, *i.e.*, chemically, or whether they mean little or nothing in that sense, and are used merely as attempted abbreviations.

Slags which are properly adjusted as to relation between oxygen in SiO_2 and in bases, may, to coin a term, be called "semi-formulistic."

It is only when a definite and chemical relation exists *between bases* as well as between silica and bases, that we can speak of a slag as a chemical formula. Only in such are we entitled to attach the full chemical significance to each and every symbol.

When we have such a requirement, and wish to compute it, we may properly translate the formula at once into its numerical equivalent. Example:

$Fe_2SiO_4 + Ca_2SiO_4$ becomes, when put into numerical expression:

$SiO_2 = 120$ $2FeO = 144$ $2CaO = 112$	or,	$SiO_2 = 15$ $2FeO = 18$ $2CaO = 14$	(or, in per cents.) : SiO_2 = 31.91 per cent. FeO = 38.30 per cent. CaO = 29.79 per cent.
			100.00 per cent.

It is not always necessary to reduce the formula to the form of an analysis.

This will probably be done sooner or later, to enable the computer to get the comparative idea which long habit has based upon percentage. But so far as "laying out" the statistics for computation is concerned, the above example is a sufficient exposition of the fact that much simpler figures than the "per cents." of an analysis will serve to introduce the same ratios.

Frequently it happens that the ratios are *very close* to simple ones, although given by rather complex figures in the preparation of the data for calculation. A case in point occurs among the examples to follow. It may little affect the practical outcome of the problem, and greatly facilitate the computation, to change the ratio over to the simple one at once. Judgment comes in here, and some perception of the extent to which the outcome will be affected. These are mental data hardly reducible to "rules."

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METHOD OF REPRESENTATIVE EQUATIONS.

In our so-called "representative" equations it will be found useful to adopt as a fixed rule 100 pounds of ore as the basis of calculation.

The *analysis* of the ore is always stated as totalling one hundred per cent. Analyses of all the other constituents of the charge will be similarly stated.

The "representative" feature of the equations is found in the adoption of the *percentages of constituents*, as the *coefficients of the unknown quantities.*

Before detailing the method, we make some general remarks on the "preparation" of the data for calculation. The item of reducing the number of bases by substitution of one for another by "conversion factors" has already been given. Another point is the fuel ratio, most important in iron, not always to be neglected in other metals. *If the fuel charge be a fixity in relation to the ore*, its ash, if it has been analysed both as to weight and composition, may be added directly to the ore analysis, so as to diminish the work of computation.

Example.—Suppose the case to be one in iron. Analysis of ore shows 8 per cent. silica. Analysis of coke shows 6 per cent. silica. Coke is to be seventy per cent. of weight of ore. Then for 100 lbs. of ore we have 70 lbs. of coke. The 100 lbs. of ore contain 8 lbs. silica; the 70 lbs. coke contain 4.2 lbs. silica (6 per cent. of 70). Add, and compute for 12.2 per cent. SiO_2 *in the ore.*

The same can be done for any other constituent. In this way the subsequent statement is simplified.

Coke ash is not usually allowed for in lead and matte smelting, though in cases where high fuel ratio combines with high ash in the fuel it might well be made an element of calculation.

In "pyritic" smelting, *i.e.*, theoretical pyritic work, where there is no coke at all, it vanishes. The case, however, is a trifle too ideal for discussion.

There are cases in iron smelting where the coke furnishes more silica than the ore. We shall sometimes include and sometimes neglect the coke ash in our examples. Its addition

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presents no difficulty, as the few extra figures required are in the "preparation" and not in the actual calculation.

Having decided upon the composition of the slag desired, we may be limited by the obstacle of having no material at hand for the production of what we seek. One or two examples will be given, but we drop this complication for the moment.

We have now the ore and fuel prepared for calculation as hitherto explained both by conversion of bases, if necessary, and by addition of fuel ash in its proper ratio to the ore analysis. We have also the analyses of the fluxes. Weights to be used of the latter are as yet uncalculated.

Call weight of the flux 100x.

Call weight of a second flux, if there be one, 100y.

The simplification thus introduced will now be explained.

The analysis is of course stated in percentages. Suppose it is a limestone we are working into the charge. It contains, let us say, 10 per cent. silica and 50 per cent. lime (CaO). We have called the weight of limestone $100x$. *Then its silica is represented by $10x$ and its lime by $50x$.*

It is not worth while to introduce fractions of percentages into the equations. *Use the nearest whole number.* If your lime was stated as 9.7 per cent., call it 10 per cent.

A little experience in working charges will soon show the student that it is often a matter of indifference whether to select the "excess" method or an equation, when there are no constituents but ore and *one* flux to consider.

But as the complexity rises, the relative simplicity of the "equation" comes out. In a calculated mixture of two ores and two fluxes, the computation and adjustment of "excess" is so troublesome that many an operator has been led into mere "fudge" figuring, trying one mix and another and checking out, until he finds one which will give results sufficiently near.

Very rarely are more than two "simultaneous" equations of the first degree called for. Although we are assuming that the reader is familiar with this very elementary algebra, we remind him that in solving by substitution (after getting value of one of the two unknowns), a small error in the value of the first unknown may produce a far greater one in the value of the second. Hence, although *after the values are obtained,* they may suffer the loss of their decimal figures without any danger to the fur-

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nace charge, this curtailment is not safe until after the equations are solved. Here comes in the ever useful "sense of magnitude." It may be born. It may be learned. It cannot be taught.

It is important to remark that the equation method has regard to nothing but percentage or numerical ratio. *Chemical proportion or "excess" does not figure in it.*

The percentages for which you are figuring, however, may be and usually are the outcome of some strict formula, itself in turn derived from either experience or theory.

But to get a result on a "formulistic" slag by this method, it is necessary to first reduce the formula to "analytical" form (100 summation) or else to a rational form, *i.e.*, one involving the chemical ratios *reduced to their simplest figures.*

Example.—We require a lime-iron slag, whose formula shall be:

$$(CaO)_2SiO_2 + (FeO)_2SiO_2$$

By Problem III, this reduces to the analysis:

SiO_2	31.9	per cent.
CaO	29.8	per cent.
FeO	38.3	per cent.
	100.00	per cent.

These figures are cumbersome to "set up" as the ratios required for the constituents (see detail of the method in first example below). They would probably be changed to 30, 30, and 40 (3, 3, 4), or to some convenient approximation.

However, it is not necessary to throw the formula into "analytical" form (see Problem I). Write out the formula, annexing the molecular weights, then reduce these to their simplest ratio. These numbers are in precisely the same ratios as their respective "percentages" in the "analytical" form, and are usually simpler.

Moreover, as they are the numbers which have to be used in getting to the "analytical" form, it is a much quicker process to use them instead of the latter. (We are, however, so accustomed to the 100 summation of ordinary analytical statement, that sooner or later every slag will be stated in that form.)

Take, then, the above formula and reduce it to molecular weight figures. Reduce the latter to their simplest ratio in whole numbers.

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$2SiO_2 = 120.$	$120 \div 8 = 15$
$2CaO = 112.$	$112 \div 8 = 14$
$2FeO = 144.$	$144 \div 8 = 18$

Now the requirement of the slag would be stated thus: "fifteen parts of SiO_2 to fourteen of lime and eighteen of iron oxide."

This is merely by way of putting the requirements into the most convenient form for computation. Arithmetically, the above statement is exactly the same as the one which gives the three percentages under the analytical summation form, with the advantage of being far simpler. The molecular weights of the three most used constituents (SiO_2, CaO, and FeO) lend themselves rather kindly to simplification of ratios.

In nine out of ten cases in actual practice, *all of this preparation is outside of the requirements.* For in most cases, the requirement will be already stated in analytical form, with very simple numbers as percentages. Thus, slag required is:

SiO_2	40 per cent.
CaO	20 per cent.
FeO	40 per cent.
	100 per cent.

In which, in "setting up" the equation the numbers may figure as 4, 2, and 4.

Illustrative Case for Method by "Representative Equations."

In order not to complicate a first illustration we take a case without any adjustment for matte, and in which we do not even state analysis of ore, *outside of its slag-forming constituents.* We also start with a requirement "ready made" as to percentages in slag (*i.e.*, no formula).

We need in this case an iron-lime slag, hence we shall assume an iron ore as well as a limestone flux. Analyses of all three follow:

	Ore, per cent.	Iron flux, per cent.	Limestone, per cent.
SiO_2	40.0	8.0	6.0
FeO	20.0	82.0	....
CaO	10.0	....	40.0
MgO	....	....	10.0

Condition as to slag.—The slag is to be composed of silica, lime and iron oxide in equal weights, *i.e.*, 33⅓ per cent. each.

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We have first to remove the slight complication of the two bases in the limestone. As given in the "conversion factors," some pages back, we multiply the magnesia by 1.4, thus getting 14 per cent. of "conventional" lime. Now the analysis of our limestone, *i.e.*, the one which is to be used in calculations, is:

LIMESTONE.

SiO_2	6.0 per cent.
CaO	54.0 per cent.

The data being now "prepared" for calculation, we proceed to make the regular assignment of "unknowns" for the fluxes, that is, represent *iron ore (lbs.) by 100x, and limestone (lbs.) by 100y.*

We take *100 lbs. of ore* as basis for calculation. *Now assemble all the expressions for silica, iron-oxide and lime.* Those derived from the ore will be in pounds direct. Those derived from the fluxes will also be in pounds *expressed in terms of x and y*, and the coefficients of these letters will be simply *the percentages as given in the analyses.*

	From ore.	From iron flux.	From limestone.
Silica	40	$8x$	$6y$
Iron oxide	20	$82x$	....
Lime (CaO)	10	....	$54y$

The condition being that each of these constituents shall be present in the slag in equal weight, we construct the two equations at sight by equating equals. Take any pair, *e.g.:*

$$(SiO_2 = FeO) \quad 40 + 8x + 6y = 20 + 82x$$
$$(FeO = CaO) \quad 20 + 82x = 10 + 54y$$

Multiplication of the first equation by 9 solves easily, giving:

$$x = 0.3253 \quad (100x = 32.53)$$
$$y = 0.6792 \quad (100y = 67.92)$$

Answer.—For each 100 lbs. of ore, take 32.53 lbs. iron flux and 67.92 lbs. limestone.

Proof.—Taking the answers, we find the weights of all the constituents of the charge. By the conditions, they should come out exactly equal.

SiO_2, from ore.	40.00	FeO, from ore.	20.00	CaO, from ore.	10.00
SiO_2, iron flux.	2.60	FeO, iron flux.	26.67	CaO, iron flux.	.....
SiO_2, limestone	4.07	FeO, limestone	.....	CaO, limestone	36.67
	46.67		46.67		46.67

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In the examples following, we begin with cases of extreme simplicity. In fact we have avoided complicated cases for the most part, when they involved nothing more than very detailed work which demanded no knowledge of principles, but merely patience in picking out and arranging data. The solving of such problems is good practice in accuracy, but not particularly "instructive."

Example.—Two ores have as slagging constituents:

	I.	II.
SiO_2	10 per cent.	20 per cent.
CaO	20 per cent.	.....
FeO	.....	60 per cent.

Take 100 lbs. of No.1. *Mix the two for slag of 30 per cent. silica.*

Solution.—Let lbs. of No. 2 = $100x$. The weights of all the constituents will now be

$$\text{Total } SiO_2 = 10 + 20x \qquad \text{Total bases} = 20 + 60x$$

By the condition, the silica is 30 per cent., the bases 70 per cent.

$$7\,(10 + 20x) = 3\,(20 + 60x)$$

Hence

$$x = 0.25 \text{ and } 100x = 25$$

Assembly and summation of the weights of each and every constituent will constitute the—

Proof:

SiO_2 from No. 1 = 10 lbs.
SiO_2 from No. 2 = 5 lbs. Total SiO_2 = 15 lbs.
FeO from No. 2 = ...15 lbs.
CaO from No. 1 = ...20 lbs. 50 lbs.

Since there are 15 lbs. SiO_2 in a total of 50 lbs., we have the 30 per cent. called for.

Example.—Take the same materials. With 100 lbs. of No. 1, add No. 2 to produce a "singulo" silicate slag.

Answer. Impossible. The SiO_2 is "short."

Proof:

In No. 1. $2CaO : SiO_2 = 1 : 0.535 = 20 : 10.70 = SiO_2$ required.
In No. 2. $2FeO : SiO_2 = 1 : 0.416 = 60 : 24.96 = SiO_2$ required.

Since neither of the ores has enough silica to satisfy its own base on the "singulo" formula, we must use some outside flux to produce a "singulo."

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Example.—Still assuming the same materials (ores Nos. 1 and 2), take 100 lbs. of No. 1, add No. 2 in such quantity as to make 2 molecules of iron oxide to 1 of lime (*i.e.*, chemical ratio), then calculate the weight of pure silica to add to the mix to bring about a singulo silicate in the slag.

The formula required is $4FeO, 2SiO_2 + 2CaO, SiO_2$.

$$CaO : 2FeO = 56 : 144 = (7 : 18) = 20 : 51.43$$

Weight of the iron oxide corresponding to twice the CaO, *i.e.*, twice as many molecules.

$$60 : 100 = 51.43 : 85.72 = \text{lbs. of ore No. 2 required.}$$

As above, we know that the CaO calls for 10.70 SiO_2. In the mix as calculated we have 27.14 lbs. SiO_2. (Prove this.)

$$27.14 - 10.70 = 16.44 \text{ lbs. } SiO_2 \text{ for FeO}$$

But 16.44 lbs. SiO_2 calls for 39.46 FeO on the formula.

51.43 − 39.46 = 11.97 FeO excess in the mix; this calls for *4.99 lbs.* SiO_2. (Parts of the operations are omitted; the student should verify the results by making full calculations for himself.)

Ans. 4.99 lbs. silica to be added.

Take the above problem from the point at which we have determined that we must use 85.72 lbs. of No. 2 ore in the mixture. We can calculate for the additional silica more quickly.

The analysis of the silicate, already formulated, is:

Silica	31.02 per cent.
Iron oxide (FeO)	49.66 per cent.
Lime (CaO)	19.31 per cent.
Total	99.99 per cent.

This formula is often calculated as $SiO_2 = 3$; FeO = 5; CaO = 2. Use this instead of the analysis, and call silica to be added "*x*."

Then we may write at once, $FeO = SiO_2 + CaO$. Or, in numbers:

$$51.43 = 27.14 + 20 + x \text{ and } x = 4.29$$

(The iron oxide required and contained in the allotted weight of No. 2 is 51.43, total silica *in the ores alone* 27.14, total lime is 20, see above.)

Now check up by adding all the constituents. The weight of 4.29 checks with the "3 : 5 : 2" proposition, though of course

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not accurately with the former figure. In practice the difference would hardly be felt.

This is an illustration of the point mentioned in the remarks preceding this section, viz: the substitution of an approximate and very simple ratio for a complex one.

In examples like these we work to practically perfect checks. Decimals of a pound are not called for in practice, but this is no argument for loose approximations in treating the subject. Short cuts are dangerous for beginners.

In presenting the "analysis" of ores in these purely slagging examples it will be understood that only the elements are given that *enter into the slag*. In matting cases the complete analyses are necessary.

Example.—We have an ore, an "iron-ore flux" and a limestone, analyses as below:

	Ore, per cent.	Iron flux, per cent.	Limestone, per cent.
SiO_2	30	10	5
FeO	5	76	..
Al_2O_3	10	5	..
CaO	..	..	53

Take 100 lbs. of the ore. Requirement for the slag is:

SiO_2	30 per cent.
FeO	40 per cent.
$CaO + Al_2O_3$	30 per cent.
Total	100 per cent.

Find weights of "iron flux" and limestone necessary.

Let $100x$ = lbs. of iron flux and $100y$ = weight of limestone.

$(SiO_2 = Al_2O_3 + CaO)$. $30 + 10x + 5y = 10 + 5x + 53y$

$(SiO_2 : FeO = 30 : 40)$. $4(30 + 10x + 5y) = 3(5 + 76x)$

$x = .609$. $y = .48$. $100x = 60.9$. $100y = 48$

Proof:

	SiO_2.	FeO.	$Al_2O_3 + CaO$.	
Ore	30.00	5.00	10.00	lbs.
Iron flux	6.09	46.28	3.05	lbs.
Limestone	2.40	.....	25.44 (CaO)	lbs.
	38.49	51.28	38.49	lbs.

These numbers are exactly as 3 : 4 : 3.

Example.—Ore, iron-flux and limestone having analyses as below, mix for a slag containing 30 per cent. SiO_2, 40 per cent. FeO, and 30 per cent. CaO.

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Take, as usual, 100 lbs. of the ore, $100x$ lbs. iron-flux and $100y$ lbs. of limestone.

	Ore, per cent.	Iron ore, per cent.	Limestone, per cent.
SiO_2	40	10	7
FeO	20	80	..
CaO	10	..	52

Operation omitted, the example being in line with those already given. The weight of the slag, per 100 lbs. of ore charged, is 172.47 lbs., and it contains 51.74 SiO_2, the same of CaO, and 68.99 lbs. FeO, numbers which are as 3 : 3 : 4.

Example.—We have two ores whose slagging ingredients are:

	I.	II.
SiO_2	40.0 per cent.	50.0 per cent.
FeO	10.0 per cent.	8.0 per cent.
ZnO	17.5 per cent.	4.0 per cent.

As fluxing material we have:

	Iron ore.	Limestone.
SiO_2	8 per cent.	5 per cent.
FeO	80 per cent.	.....
CaO	.....	50 per cent.

Mix the two ores for zinc oxide tenor of 7 per cent. then for 100 lbs. of the mix find lbs. of iron flux and limestone to make, *irrespective of zinc*, a slag whose per cent. composition shall be:

SiO_2	30 per cent.
FeO	50 per cent.
CaO	20 per cent.

Also give analysis of the slag, zinc included, under the supposition that there is no loss of zinc in smelting.

Applying the "mixing" rule, we have $17.5 - 7 = 10.5$ and $7 - 4 = 3$. Take, therefore, 3 parts of No. 1 to 10.5 parts of No. 2, or 1 part of No. 1 to $3\frac{1}{2}$ parts of No. 2. This gives the required 7 per cent. of zinc oxide, also the following for other percentages of the mixture: $SiO_2 = 47.77$; $FeO = 8.44$. Let $100x$ = iron flux, $100y$ = limestone.

The equations are:

$$(1)\ 47.77 + 8x + 5y = .6 \times (8.44 + 80x)$$
$$(2)\ .4 \times (8.44 + 80x) = 50y$$

Iron flux = 116.8, Limestone = 81.5 lbs.

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Proof:

	SiO_2.	FeO.	CaO.	(ZnO.)
In 100 lbs. ore.....	47.77	8.44	.....	7.0
In 116.8 lbs. flux.....	9.34	93.44	.....	...
In 81.5 lbs. limestone.....	4.07	.....	40.75	...
	61.18	101.88	40.75	

These numbers are as 3 : 5 : 2. Analysis of the slag, zinc included:

SiO_2.....	29.02 per cent.
FeO.....	48.33 per cent.
CaO.....	19.33 per cent.
ZnO.....	3.32 per cent.
	100.00 per cent.

Example.—For single equation. Slagging constituents of ore, SiO_2 = 20 per cent., FeO = 15 per cent. Limestone, SiO_2 = 10 per cent. Bases, 50 per cent. Mix 100 lbs. ore with limestone for 40 per cent. SiO_2 in slag.

Operation omitted. One unknown quantity is needed.

Ans. Limestone = 42.857 lbs.

Analysis of slag:

SiO_2.....	40.00 per cent.
FeO.....	24.70 per cent.
Bases.....	35.30 per cent.
	100.00 per cent.

Example (this is an arithmetical exercise, not a slag problem).—We have used 1,000 lbs. of ore in a charge, containing 30 per cent. SiO_2. Also charged 600 lbs. of iron-ore flux and 600 lbs. limestone, whose compositions were respectively as follows: Iron flux, SiO_2 = 15 per cent., FeO = 75 per cent. Limestone, SiO_2 = 10 per cent., CaO = 50 per cent.

The slag analyzes: SiO_2 = 30 per cent.; bases, 70 per cent.

What was the percentage of slagging bases in the ore?

Operation omitted. *Ans.* 30 per cent.

Example (also a mere piece of arithmetic).—Use silicon = 28.4 in the calculation.

An iron ore contains SiO_2, 15 per cent.; FeO, 85 per cent. The pig metal contains all of the iron from the ore, and analyzes: Carbon, 3.5 per cent.; silicon, 2.5 per cent.

What percentage of silica in the ore was reduced to silicon?

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Operation omitted. Answer, 3.37 per cent. of the silica is reduced.

Some examples more complex will now be considered at length. A general method, however, is better set forth by the use of simple cases like the preceding than by problems of greater detail, whose complications often serve to mask the simplicity of the principles involved.

In order to illustrate how the equation method operates in cases where there are *percentages of each element in each material* (ore, iron flux, and lime) we here give such a case, in which we are to suppose that the analyses as presented have been simplified by extraction of matting constituents, and reduction of the various bases to the two groups, iron and lime. As this is intended merely as an example of the adaptation of equations to the case mentioned, the coefficients have been made extremely simple.

Example.—Ore, iron flux, and limestone, reduced to simplest forms, and none but slagging bases given:

	Ore.	Iron ore flux.	Limestone.
SiO_2	40	10	4 per cent.
FeO	20	72	6 per cent.
CaO	10	10	50 per cent.

Conditions.—Slag to be: SiO_2, 40 per cent.; FeO, 40 per cent.; CaO, 20 per cent.

Solution.—Call iron and lime fluxes as usual, $100x$ and $100y$. Ore, 100 lbs.

$$(1)\quad 40 + 10x + 4y = 20 + 72x + 6y$$
$$(2)\quad 40 + 10x + 4y = 20 + 20x + 100y$$

(1) Reads: "Weight of silica equals weight of iron oxide."

(2) Reads: "Weight of silica equals twice weight of lime."

$x = .3169$ $y = .1753$ $100x = 31.69$ $100y = 17.53$.

Ans. Iron flux, 31.69 lbs.; limestone, 17.53 lbs.

Proof.—All SiO_2 from ore = 40.00, from $10x = 3.17$, from $4y = .70$.

Total $SiO_2 = 43.87$ lbs.

All FeO from ore = 20.00, from $72x = 22.82$, from $6y = 1.05$.

Total FeO = 43.87 lbs.

All CaO from ore = 10.00, from $10x = 3.17$, from $50y = 8.765$.

Total CaO = 21.935. $21.935 \times 2 = 43.87$.

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The weights reduce to 40 per cent., 40 per cent., and 20 per cent.

This case would make a very complex problem if any method by "excess" were attempted. It illustrates the point that as conditions multiply, the "equation" method becomes relatively simpler.

Conditions which render a problem impossible are not always recognizable at first glance. Suppose we have the following analyses:

	Ore, per cent.	Iron ore flux, per cent.	Limestone, per cent.
SiO_2	30	10	10
FeO	30	80	..
CaO	10	..	50

The requirement is a slag which shall analyze SiO_2, 40; FeO, 40; CaO, 20 per cent. It looks as though no more iron should be added, since the proportion of iron oxide in the ore exactly balances the silica according to required formula. But the lime is lower than the required ratio, so we have to add limestone. If the limestone were absolutely pure—*i.e.*, if it had no silica, we could use it alone, and get the slag called for. But in adding it, we add silica, thus disturbing the ratio of silica to iron. In short, we need some of the iron ore in our charge. Take, as usual, 100 lbs. ore.

Here we omit both statement and operation, giving only answer and proof.

Answer:

Iron flux required to 100 lbs. of ore, 1.613 lbs. ($100x$)
Limestone required for same, 11.29 lbs. ($100y$)

Proof:

SiO_2, from ore...	30.00	FeO, from ore..	30.00	CaO, ore...	10.00
SiO_2, $10x$.....	.16	FeO, $80x$	1.29	CaO, $50y$...	5.645
SiO_2, $10y$.....	1.13				
	31.29		31.29		15.645

These weights check absolutely to the required ratio, making slag as required, 40 : 40 : 20, for SiO_2, FeO, and CaO. Yet the problem looks hardly possible, to exact figures, on hasty inspection.

We might have a little *more* iron than silica in the ore, and still have to add iron flux. Thus, keeping all of the data of the last problem, except the per cent. of iron oxide in the ore if we raise

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that to 31 per cent. (instead of 30) we shall find that an exceedingly minute portion of the iron flux still has to be added, though now it becomes so small as to be absurd as a practical addition (0.1613 lb.).

Again we raise the per cent. of FeO in the ore, this time to 32. State the conditions in the usual way ($100x$ for iron flux, $100y$ for limestone). You will now get a small *minus* value for x, the usual "notice" that you are attempting an impossible problem.

Without illustrating by further examples, the general case may be thus stated, the materials given being understood to be (1) the ore, (2) an iron oxide flux, (3) a limestone. It is also understood that the flux and the limestone are never pure, but always contain some percentage of silica. *But both the fluxing materials are to be basic—i.e.*, holding base in ratio far above silica. By "iron" and "lime" we understand the "groups" already given.

If, in the ore, both the bases are below the required ratio to silica, the problem is solvable.

If one is equal to the required ratio, and the other below it, the problem is still possible, but only under certain conditions as to analyses—*i.e.*, solvable within certain limits.

If both happen to be in the required ratio, then the ore is charged as self-fluxing, needing no additions.

If one base is lower and the other higher than the requirement, then the problem is solvable only within certain limits (as shown above).

If both bases are higher in ratio than called for, the problem is impossible.

Impossible, that is, under the conditions imposed. Practically solvable by adding silica or highly siliceous material in proper proportion, to the charge, instead of the fluxes, which, as above, are supposed to be always basic.

The following problem, as to its data, is from Prof. Edward D. Peters's fine work on the "Principles of Copper Smelting," 1907.

"We take, for a final comprehensive illustration, a copper-gold-silver ore of such a nature that it will not, when smelted by itself, yield a proper slag. We will assume also that we have at our disposal certain suitable fluxes and fuel. From the analyses

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of these substances we will determine how we must mix them so that they may, on smelting, yield a slag of the composition that we desire, and a matte of suitable grade." ("Principles of Copper Smelting," page 118.)

Professor Peters then proceeds to explain all the simplifications called for, the requirement for the slag being:

Silica	38 per cent.
Iron oxide (FeO)	50 per cent.
Earths	12 per cent.
	100 per cent.

It will be noted that all of the basic slagging constituents except iron oxide are thrown together under the general classification of "earths," a proceeding justified in the present case, as, without here repeating all the original analyses and simplifications, we may state in brief that owing to the small quantities of alumina and magnesia, it serves all practical purposes to add them together without troubling ourselves to "convert" them by the factors already discussed into their chemically "equivalent" lime basis. This is set forth by footnote, page 123 of the "Principles."

The calculation starts from a roasted ore, which is supposed to be the carrier of the chief values in precious metals. For fluxing material we have a *hematite ore* and a *limestone*.

We have also the coke, whose ash is included in the computation for slag. Thus we start with four elements of computation, requirement for slag composition as above being the condition by which we have to regulate the charge.

Professor Peters assumes 100 lbs. ore as basis of calculation.

As the present elucidation concerns only the calculation of the slag, we shall not go into all the physical reasoning and the details of supposed losses of copper and sulphur, which result in subtractions from the original analyses.

What we wish to show in the present discussion is chiefly the difference in method of slag calculations; and since there are no differences in the "simplifications" of data prior to such calculations, we shall omit the discussion in the text (pp. 117–124) and assume precisely the same simplified analyses of ore, hematite and limestone as are arrived at finally in Professor Peters' discussion, which he gives on page 125.

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It will be noted that the analyses are given before computing the matte. It is at this very point that we make our first departure from the method in Professor Peters' text, as we take the iron for matte from the ore itself, instead of from the hematite.

But for this, we should present the analysis freed from even the matte subtractions. As it is, we adopt all of Professor Peters' simplifications *up to this point*, and then proceed with our "representative equations."

After then, adding MnO to FeO, and throwing all other basic constituents together as "earths," we arrive at the "simplified analysis." The ore is supposed to be roasted, and we here omit, as wholly outside of the scope of this illustration, the values of the precious metals in the original analyses.

They are, indeed, omitted by Professor Peters in the analysis annexed.

In short, as the simplification is along precisely the lines we have already set forth, it would be a waste of space for us to do otherwise than to start the slagging problem proper from any other point than where it is started in the text quoted.

"SIMPLIFIED ANALYSES." (Peters, p. 125.)

	SiO_2.	FeO.	Earths.	Cu.	S.
Silicious ore	42.0	30.6	5.6	5.76	4.8
Hematite	5.0	75.6	5.9		
Limestone	3.3	3.9	49.1		
Coke ash	42.6	22.2	32.1		

We have now to explain that the coke is assumed at 12 per cent. of the ore charge. We are to compute on the basis of 100 lbs. ore, consequently we shall calculate for 12 lbs. coke. Ash of the coke stated at *12 per cent.*

At this point we part company with the text quoted, and proceed to calculate the required charge by "representative equations."

The calculation in the "Principles" goes upon chemical excesses, and as will be seen arrives at a result practically the same as ours. But this being a case where the composition of the required slag is given *in percentages* there is not the slightest occasion to consider any chemical relations. *They are properly out of consideration as soon as we have gone to the "percentage" basis of calculation.*

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We must first get the matte "out of the way." This being done by the method of excess already explained, no further chemical question shall interfere from that point to the end.

As usual assume that Cu_2S will be the form of the copper in the matte. This disposes of copper and part of sulphur, as follows:

$$4 : 1 = 5.76 : 1.44$$

Then, adding the two last numbers, expressing copper and sulphur combined with it, we have for the copper component of the matte 7.20 lbs. per 100 of ore.

The "residual" sulphur is $4.8 - 1.44 = 3.36$.

Adjust this to as much FeO as is required for the formation of FeS.

$$\begin{matrix} 32 : & 72 & = 3.36 : & 7.56 \\ S & FeO & S & FeO \end{matrix}$$

We are then to subtract 7.56 FeO from the ore, as allowance of what is to be taken out in the matte. This 7.56 FeO corresponds to 5.88 Fe, too simple a calculation to be repeated here. We have then to add the residual sulphur to this iron, $5.88 + 3.36 = 9.24$ = iron component of the matte.

Matte to 100 lbs. ore charge:

As above, Cu_2S	7.20 lbs.
FeS	9.24 lbs.
Total calculated matte fall per 100 lbs	16.44 lbs.

Since the coke, consequently its ash, is in fixed ratio to the ore, we may at this point combine its analysis with that of the ore, thus ridding ourselves of a complication at the outset. The coke has 12 per cent. ash, and is itself 12 per cent. of the ore charge. That is, coke ash per 100 lbs. ore charge is $12 \times .12 = 1.44$ lbs. Calculate from the analysis of ash above the lbs. or fractions of its several constituents, and add results in proper places in ore analysis.

Thus, using analysis and weight (1.44 lbs.), we have—

Ash, distributed as to constituents to be added to ore analysis:

SiO_2	$.426 \times 1.44 = 0.6$ lbs.
FeO	$.222 \times 1.44 = 0.3$ lbs.
Earths	$.321 \times 1.44 = 0.5$ lbs.

We have dropped decimals in second place, as too trivial to "bother" with in a constituent itself rather trivial.

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Remembering that we had in our matte allowance to subtract 7.56 from FeO, we can now tabulate our final analysis, ready for calculation.

If we then drop all fractional parts of the percentages, as would certainly be done in practice, we shorten our work considerably. In order, however, to demonstrate how little difference such abbreviations make, we shall in this instance, *after* solving with simplified coefficients, return to the original analysis as here annexed, and taking in all the fractional numbers, construct the equation with all these fractions in it, arriving, as will be seen, at a result so close to the first that one result is as good as another.

However, the first analysis as here tabulated retains the fractions.

Silica: To 42 lbs. in ore analysis above, add 0.6 lbs. from coke ash.. 42.60
FeO: To 30.6 lbs. in same, *add* 0.3 (coke), *subtract* 7.56 (matte).. 23.34
Earths: To 5.6 lbs. in same add 0.5 from coke ash..... 6.1

This completes the "clearance," first for matte and second from the little complication of the coke ash. The latter would hardly be regarded in actual practice, but is retained and calculated in, both because it is well to understand such details, and because it is allowed for in the text we have started from.

We shall now state the full analysis, calling it, for reference, analysis "A." We shall then restate it, dropping fractional figures, and shall call the latter analysis "B."

Analysis "A":	SiO_2.	FeO.	Earths.
Ore (coke ash included).....	42.6	23.34	6.1
Hematite.....	5.0	75.6	5.9
Limestone.....	3.2	3.9	49.1

Analysis "B":	SiO_2.	FeO.	Earths.
Ore.....	43	23	6
Hematite.....	5	76	6
Limestone.....	3	4	49

In practice, analysis "B" would be accepted, as simpler and close enough.

Find required weights of hematite and limestone.

Calculation of charge starting with analysis "B."

Call weight of hematite $100x$.

Call weight of limestone $100y$.

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The equations are all in "pounds" since the basis is 100 lbs. of ore.

Now get together the "representative" terms, SiO_2, FeO, and "Earths."

$$\begin{aligned} \text{Silica} &= 43 + 5x + 3y \\ \text{FeO} &= 23 + 76x + 4y \\ \text{Earths} &= 6 + 6x + 49y \end{aligned}$$

These come directly from the vertical columns of the analyses. For example, the SiO_2 in the 100 lbs. ore is 43 lbs. Since SiO_2 in hematite is 5 per cent. it is 5 per cent. of $100x$, that is, $5x$; similarly the SiO_2 in the limestone is $3y$.

Apply the same method to the other constituents, and we get the three expressions above.

Refer to the slag condition as given at the opening of this problem.

The silica is to be to the "earths" as 38 to 12. So state it:

$$38 : 12 = (43 + 5x + 3y) : (6 + 6x + 49y) \qquad (1)$$

The FeO is to be to the "earths" as 50 to 12. So state it:

$$50 : 12 = (23 + 76x + 4y) : (6 + 6x + 49y) \qquad (2)$$

As we need but two equations the statement is complete.

Solve the equations:

$x = 0.4821$, $100x = 48.21$	Hematite for 100 lbs. ore charge 48.21 lbs.
$y = 0.1133$, $100y = 11.33$	Limestone for 100 lbs. ore charge 11.33 lbs.

Nothing remains as to solution. But if we desire to check up our results the procedure is easy, and is here given at length.

Proof.—Taking the weights as found, for hematite and limestone, we ascertain by multiplication the respective weights of SiO_2, FeO, and of "earths" in each, add them to already known weights of these constituents in the ore, and obtain total for each constituent in the slag.

If these prove to be in the required ratio (38 : 50 : 12), the proof is absolute.

	Silica.	FeO.	Earths.
From ore	43.00	23.00	6.00
From hematite ($5x$)...	2.41	($76x$) 36.64	($6x$) 2.89
From limestone ($3y$)..	0.34	($4y$) 0.45	($49y$) 5.55
Totals	45.75	60.09	14.44

Total weight of slag per 100 lbs. of ore charged, with the above found weights of fluxing material, is 120.28 lbs.

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Then, testing the ratios of the three weights as in the above proof, for the three constituents, too simple an operation to be inserted, we find:

$$38 : 50 : 12 = 45.75 : 60.09 : 14.44$$

The "proof" then is absolute, and the only error is in the slightly abbreviated coefficients, which is the same as a slight alteration in the analyses.

We shall now restate the equations, not because there is any difference in principle, but to show what an immaterial matter this dropping of decimals really is. Note that from start to finish of the "setting up" of the problem there has been *no chemical adjustment whatever;* none was needed.

Turn now to analysis "A" and write the two equations as before.

$$38 : 12 = (42.6 + 5x + 3.2y) : (6.1 + 5.9x + 49.1y) \quad (1)$$
$$50 : 12 = (23.34 + 75.6x + 3.9y) : (6.1 + 5.9x + 49.1y) \quad (2)$$

No difference except that we have now used as coefficients the original percentage figures, with their fractional parts.

Solving these as before we get:

$x = 0.4752$, $100x = 47.52$ Hematite = 47.52 lbs. to 100 lbs. ore
$y = 0.1102$, $100y = 11.02$ Limestone = 11.02 lbs. to 100 lbs. ore

Proof is accomplished just as before. We find that the total weight of the slag per 100 lbs. ore charged is 119.33, but the percentages of SiO_2, FeO and "earths" come out as before, viz: 38 : 50 : 12.

The ordinary method of solution of such cases puts the ingredients into groups, after carefully adjusting the elements of each according to the slag requirement, and calculating "excess" of one element over another, in ore, hematite and limestone, first *within themselves, i.e.*, finding excess of silica in ore, of iron in hematite, and of lime in limestone; and afterwards the adjustment of these ingredients thus prepared as to "available" elements, *to one another.*

It is a tedious and *entirely useless* proceeding. The assignment of any "percentage" (as here, 38, 50, 12) throws out of consideration all necessity of further treatment of chemical "excess."

The "representative method" is perfectly general in its application. The above case can be deliberately figured from equation to answer in ten minutes.

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ILLUSTRATION OF "REPRESENTATIVE" METHOD IN COMPLETE IRON FURNACE PROBLEM.

The following problem is taken, as to data and conditions, from the *Engineering and Mining Journal* of New York, August 24, 1907. It is there presented by Prof. Bradley Stoughton, of Columbia University.

The method of solution is of course totally different. From the nature of the "representative" method, there are no trial results and no re-calculations.

An impossible analysis forms part of the original data, viz: in ore No. 1, which by some slip is represented as containing 21 per cent. impurities and 60 per cent. metallic iron. This implies the existence of an oxide containing over 75.9 per cent. iron. The analysis is retained, however, so as to make the problems identical.

The slight variant in the answer is due partly to method, and partly to omission of certain small data in the original solution in the *Journal.*

The materials to be used are two iron ores, coke and limestone. Analyses of the ores and limestone, also of the *ash of the coke,* are as below.

	Ore No. 1.	Ore No. 2.	Coke ash.	Limestone.
SiO_2	11.00	16.00	50.00	4.00 per cent.
Al_2O_3	2.00	12.00	18.00	2.00 per cent.
Fe	60.00	50.00	10.00	2.00 per cent.
CaO	5.00	2.00	20.00	46.00 per cent.
MgO	3.00	.....	.....	3.00 per cent.

It is settled that we shall use 10,000 lbs. coke to 18,000 lbs. ore. As allowance for silicon in the pig metal it is agreed that we shall subtract *one per cent.* from the silica in each ore. That is, in the calculation we take 10 as SiO_2 per cent. in No. 1, and 15 as SiO_2 per cent. in No. 2.

In order to reduce bases (hence complication of calculation) we first apply the factor 1.4 to the magnesia, and add result to the lime figures in ore No. 1 and limestone. Neglecting the fraction 0.2, this gives us 9 per cent. lime in ore No. 1 and 50 per cent. lime in the limestone. *The ash is ten per cent. of the coke.*

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Condition for the Slag.—We are to mix the ores for the 18,000 charge and add limestone so as to produce slag of the following composition:

Silica	30.00 per cent.
Alumina	15.00 per cent.
Lime	55.00 per cent.
	100.00 per cent.

Remember that the *total weight* of ore is fixed at 18,000 but the *relative weights* of the two kinds are to be determined. The coke is a fixed weight, *i.e.*, 10,000 lbs. The "unit" of the equations is *in lbs.*

Let $100x$ = lbs. of ore No. 1., $100y$ = lbs of ore No. 2.

Let $100z$ = lbs. of limestone. Weight of coke is 10,000 lbs.

First. Equate sum of ore weights with given figures, *i.e.*,

$$100x + 100y = 18{,}000 \qquad (\text{Or, } x + y = 180)$$

Second. Equate the condition that $SiO_2 = 2 \times Al_2O_3$, *i.e.*,

$$10x + 15y + 4z + 500 = 4x + 24y + 4z + 360$$

In this equation the 500 in first member is absolute weight in lbs. of the silica in the coke, *i.e.*, 50 per cent. of 10 per cent. of 10,000 = 500.

The 360 in second member is *twice* weight of alumina derived in exactly the same way from the 10,000 lbs. and the 18 per cent.

The "z" eliminates at once, so that we solve these two with x and y only, readily obtaining:

$$x = 98.6667 \text{ or } 100x = 9866.67 \text{ lbs. of No. 1 ore}$$
$$y = 81.3333 \text{ or } 100y = 8133.33 \text{ lbs. of No. 2 ore}$$

But as we must get a value for z, we next equate the condition that

$$SiO_2 : CaO = 30 : 55$$

That is, putting the expressions for total SiO_2 and total CaO in their places, and equating product of means with product of extremes, we have:

$$55\,(10x + 15y + 4z + 500) = 30\,(9x + 2y + 50z + 200)$$

But we have already the values of x and y and have only to substitute them, thus getting:

$$z = 86.9888 \text{ and } 100z = 8698.88 \text{ lbs.}$$

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Charge for the furnace:

Ore No. 1	9866.67 lbs.
Ore No 2	8133.33 lbs.
Limestone	8698.88 lbs.
Coke	10000.00 lbs.

It remains only to check these results, *e.g.*, figure by substitution actual silica and actual alumina, and compare according to condition for the slag. They should be as two to one in weight. So also for lime.

1st. Figure out total silica. To do this, take weights of the various constituents as found, and percentages of silica as given by the analyses. Remember the subtractions of 1 per cent. from each ore.

Silica from ore No. 1	986.667 lbs.
Silica from ore No. 2	1220.000 lbs.
Silica from coke	500.000 lbs.
Silica from limestone	347.955 lbs.
Total silica	3054.622 lbs.

2nd. Figure out total alumina. Proceed exactly as above.

Alumina from ore No. 1	197.3334 lbs.
Alumina from ore No. 2	975.9996 lbs.
Alumina from coke	180.0000 lbs.
Alumina from limestone	173.9776 lbs.
Total alumina	1527.3106 lbs.

Now compare these two weights:

$1527.31 \times 2 = 3054.62$ exactly as required, since the proportion of silica in slag is to be twice that of alumina, *i.e.*, 30 : 15.

3rd. Figure out total lime and compare it with either silica or alumina. We here make the comparison with silica.

CaO from ore No. 1	888.0003 lbs.
CaO from ore No. 2	162.6666 lbs.
CaO from limestone	4349.4400 lbs.
CaO from coke	200.0000 lbs.
Total lime	5600.1069 lbs.

The "proof" then is absolute.

Total SiO_2 as above 3054.622.

The numbers for total silica and total lime are as 30 : 55, as they should be.

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Useless Complications in Slag Calculations.

In many works when a method of slag computation is introduced, the data for the slag being given *in percentage* (as in problems above), it is nevertheless given as part of the procedure to adjudicate between elements in the same flux addition, and determine "excess."

This mixture of methods is useless, and attention is especially called to the fact that in the present method, when once the percentage (or what is the same thing, the ratio of elements in the required slag) is a fixed requirement, *all chemical questions vanish.*

It is worse than useless to bring in any question of "excess" in the representative method. It is a mere complication, with no compensating advantage.

E.g., suppose that our limestone contains nothing but carbonate of lime and silica—lime 53.2, and silica 5 per cent.

Figuring on "singulo" basis this gives lime excess of 43.9 per cent.

But in the "representative" method this cuts no figure. The silica and the lime of this and any other ingredient of the charge *are all included in the equations*, and the result is a perfect adjudication of all the elements on the basis of the required composition.

Again there are no "trial" figures, and no "re-adjustments" in the method. The statement once made, the solution of the equations gives the final figures. It is recommended that no variation be made from the basis of 100 lbs. as the ore unit of calculation. This was indeed violated in some examples, but uniformity of practice leads to greater safety.

The method, however, is independent of any rule or usage of this kind.

Type Slags often Found in Metallurgical Practice.

Necessity, or the proper selection of the most economical material, may often determine the composition of a furnace charge, especially in cases where a considerable latitude is allowable without danger to the running.

Iron.—Almost invariably, the sole addition for fluxing purposes in iron smelting is limestone. Excepting manganese, in

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smelting for "spiegel eisen" (on special manganiferous ores), alumina will be the chief base in the ore, and is often insignificant in amount. *The general rule is followed to figure for a "singulo" slag*, without reference to the proportions of bases among themselves. Beyond this it is hardly necessary to go.

No fear need be entertained because of the presence of a moderate percentage of magnesia in the limestone. Many iron men prefer to use a magnesian lime. However, it is well known that lime reduces the sulphur contents of the pig iron more certainly than magnesia, so that, in smelting sulphurous ores, a limestone low in magnesia should be selected.

Copper.—In matte smelting it is rarely possible to select material so as to produce a slag of exact pre-arranged formula or percentage. It has already been remarked that in pyritic smelting there is a wide margin for the outcome, owing to the single fact that we cannot predict just what the oxidation of iron will be (*i.e.*, from pyrites), hence a corresponding variation as to ratio between slag and matte.

A table is here given showing allowable variations of the constituents of slags from the copper furnace. According to the principles of replacement, manganese classes as iron, barium and magnesium as lime.

Slag constituent.	Minimum.	Maximum.
Silica	26	45 per cent.
Alumina	0	20 per cent.
Iron oxide (FeO)	18	65 per cent.
Lime	0	28 per cent.
Zinc oxide (ZnO)	0	14 per cent.

Lead.—The following table, as well as the preceding one (for copper slags) is taken from the "Manual of Practical Assaying" of the late Howard van F. Furman. (Sixth edition, 1908.)

A great number of "formulæ" for slags in lead smelting have been published, but as their discussion is somewhat outside of our scope, we content ourselves with the presentation of the following figures.

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TYPICAL LEAD SLAGS.*

Number.	Silica, per cent.	FeO, per cent.	Lime, per cent.	ZnO, per cent.
1	35	28	28	....
2	34	34	24	....
3	34	34	17	7
4	30	40	20	....
5	30	48	12	....
6	28–30	54	6	....

ADDITIONAL EXAMPLES OF "REPRESENTATIVE" METHOD.

In these examples we give cases for each of the metals, iron, copper and lead, also a case for the mixing of three ores ("self fluxing").

Whole units only are given in the analyses. The supposition is that the analyses have been adjusted to the nearest units to simplify calculations.

These alterations of less than the half of one per cent. on any one constituent can never materially affect the outcome.

Thus, if we have material analyzing as below, viz:

Silica	10.7 per cent.
Alumina	8.2 per cent.
Magnesia	3.9 per cent.
Ferric oxide	77.2 per cent.
	100.00 per cent.

We "adjust," in order to get simple coefficients, by dropping or adding, so as to get the nearest unit, keeping summation at 100, thus:

Silica	11.00 per cent.
Alumina	8.00 per cent.
Magnesia	4.00 per cent.
Ferric oxide	77.00 per cent.
	100.00 per cent.

* These percentages do not sum to 100. The deficit is supposed to be made up by bases not indicated in the analysis, or at least neglected in the calculations. It is a common though not accurate method of figuring slags.

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The subject of matte estimation is of practical bearing, and too closely connected with local or special conditions to be made part of a work on calculations except in the broad way already indicated. The student is referred to Professor Peters' works, "Modern Copper Smelting" and "Principles of Copper Smelting," also to Lang's "Matte Smelting," for information.

(1) **Slag Calculation for Iron Blast-Furnace.**—Assume that coke will be one-half the weight of the ore. The ash of the coke is twelve per cent. of the coke weight.

Analyses:

	Ore.	Coke ash.	Limestone.
SiO_2	13.00	82.00	4.00
Al_2O_3	9.00	18.00	....
Fe_2O_3	78.00	....	....
CaO	....	....	43.00
MgO	....	....	9.00

Take 3 per cent. of silica from ore analysis, for silicon in the pig.

Condition for the slag is simply that it shall contain 35 per cent. silica. Find weight of limestone to be taken per 100 lbs. of ore. Also find weight of slag for each 100 lbs. of ore taken, and calculate analysis of the slag. Work out a "check" on the whole computation.

This is to be worked under the "representative" method with one unknown quantity.

Let $100x$ = lbs. of limestone required per 100 lbs. ore.

Charge will be 100 lbs. ore + 6 lbs. coke ash + $100x$ lbs. limestone.

Silica from ore figured at 13 − 3 = 10 per cent.

As the requirement is for percentage of silica only, all of the bases are added together without regard to their chemical equivalencies.

Neglect fraction in calculating silica and base from the coke ash.

Note that since the coke is assumed at one-half the ore, we have 50 lbs. coke to the charge of 100 lbs. ore, hence 6 lbs. ash to the charge.

Charge in pounds:

	Silica.	Bases.
From ore	10.00	9.00
From coke	5.00	1.00
From limestone	$4x$	$52x$
Totals	$15 + 4x$	$10 + 52x$

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But, since silica is to be 35 per cent., bases must be 65 per cent., that is:

$$15 + 4x : 10 + 52x = 35 : 65$$

Whence $x = 0.4$ and $100x = 40$ = lbs. limestone to the charge.

Total charge is, *Ore, 100 lbs.; Coke, 50 lbs.; Limestone, 40 lbs.*

Proof.—Silica in lime being 4 per cent., its weight in 40 lbs. = 1.6 lbs.

Bases in lime are 52 per cent., their weight in 40 lbs. = 20.8 lbs. Hence:

Silica = 10 + 5 + 1.6	16.6 lbs.
Bases = 9 + 1 + 20.8	30.8 lbs.
Weight of slag	47.4 lbs.

Also, since 16.6 is 35 per cent. of 47.4, the slag "checks."

Composition.—By multiplying by the various percentages of alumina, lime and magnesia and adding, we get:

Silica	16.6 lbs. or	35.02 per cent.
Alumina	10.0 lbs. or	21.09 per cent.
Lime	17.2 lbs. or	36.29 per cent.
Magnesia	3.6 lbs. or	7.60 per cent.
	47.4 lbs.	100.00 per cent.

Variation in the coke burden would call for some change in the limestone, though a silica variation in the slag of a unit or two is nothing.

(2) **Slag Calculation for Copper-Matte Operation.**—The charge is confined to ore, coke and limestone. Coke to be twelve and a half per cent. of the ore. The coke has 16 per cent. ash. As shown by the analysis, the ore is supposed to be partly roasted or else partly oxidized as mined. Analyses as below:

	Ore.	Ash of coke.	Limestone.
Silica	30.00	80.00	7.00
Alumina, etc	13.00	20.00	CaO, 52.00
Iron (metallic)	28.00	....	....
Copper	6.00	....	....
Zinc	6.00	....	....
Sulphur	12.00	....	....
Oxygen (deficit)	5.00	....	....
	100.00		

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The following assumptions are made as to division of the elements in the matte and slag:

All copper goes into matte as Cu_2S.

One-half of the iron goes into matte as FeS.

One-half of the zinc goes into matte as ZnS.

Half of the iron and half of the zinc go into the slag as FeO and ZnO, respectively. All other bases go into the slag (Al_2O_3, CaO).

Slag condition limited to: "Silica 40 per cent., all bases 60 per cent." That is, no stated ratio as between lime and other bases is called for.

The assumptions as to matte do not account for all of the sulphur. The excess is supposed to be burnt or dissipated. Thus, on the usual basis of 100 lbs. ore:

Iron, 14 lbs., requires for FeS	8 lbs. sulphur
Copper, 6 lbs., requires for Cu_2S	1.5 lbs. sulphur
Zinc, 3 lbs., requires for ZnS	1.5 lbs. sulphur

Thus the total matte produced per 100 lbs. ore is assumed as 34 lbs. Percentage composition as follows:

Iron	41.2 per cent.
Copper	17.6 per cent.
Zinc	8.8 per cent.
Sulphur	32.4* per cent.
Total	100.00 per cent.

Slag Computation.—The slag may now be calculated by one equation with one unknown quantity. Statement is as follows:

Ore	100 lbs.
Coke	12.5 lbs.
Limestone	$100x$ lbs.

Now assemble the constituents and sum them, as below:

	Silica.	Iron oxide.	"Bases."
Ore	30.0	18.0	17.0†
Coke	1.6‡	....	0.4‡
Limestone	$7x$	....	$52x$
Totals	$31.6 + 7x$	18.0	$17.4 + 52x$

* Few mattes will contain such a percentage of sulphur. This does not invalidate the problem as an exercise in *computation on fixed assumptions.*

† Al_2O_3, 13 lbs.; ZnO, from 3 lbs. zinc (not quite), 4 lbs.; total, 17 lbs.

‡ Coke has 16 per cent. ash, 12.5 lbs. are used, making 2 lbs. ash. Eighty per cent. of this = 1.6 lbs. silica. Twenty per cent. = 0.4 lb. bases.

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Statement is "Silica is to bases as 40 : 60 (or as 2 : 3). Adding the 18 lbs. iron oxide to the other bases, we have:

$$3\,(31.6 + 7x) = 2\,(35.4 + 52x)$$

Hence, $x = 0.2892$, and $100x = 28.92$ = *lbs. of limestone to be added for each 100 lbs. of ore.*

Proof.—Silica in limestone is 7 per cent. of 28.92 or 2 lbs.

Lime in limestone is 52 per cent. of 28.92 or 15 lbs. Hence summation for the slag is as follows:

	Silica.	Bases.
Ore	30.0	35.0 lbs.
Ash of coke	1.6	0.4 lbs.
Limestone	2.0	15.0 lbs.
Totals	33.6	50.4 lbs.

Finally: $33.6 \times 3 = 100.8$, and $50.4 \times 2 = 100.8$, that is, the requirement is fulfilled that silica: bases = 40 : 60.

(3) **Slag Calculation for Lead Smelting.**—The requirement in this case will be for a slag proportioned thus: Silica, 30 per cent., iron oxide, 40 per cent.; lime, 20 per cent.; which practically assumes 10 per cent. of bases other than FeO and CaO.

It will be seen that *exact* compliance with such a condition is not practicable, since it would be only by accident that materials fitting precisely into the specified composition could be found.*

In practice, this allowance meets actual average fairly well.

The "90 per cent." adjustment is a mere convention, but as it is often used, it is well to show that the "representative" method adapts itself to the same without the slightest modification.

Analytical Data.—Materials to be used on above requirement.

	Ore.	Iron flux.	Limestone.
Silica	55.0	12.0	10.0 per cent.
Alumina	3.0	3.0	.... per cent.
Lime (CaO)	....	....	50.0 per cent.
Iron	9.1	(FeO) 85.0	.... per cent.
Lead	19.0	....	.... per cent.
Zinc	4.0	....	.... per cent.
Copper	2.0	....	.... per cent.
Sulphur	5.7	....	.... per cent.
Deficit (oxygen ?)	2.2 (summation for ore = 100 per cent.)		

* The three mentioned can be brought in, in proper ratio, not the "accident."

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Before calculating the slag let us "take out" the matte. Assuming the usual 100 lbs. (ore) as basis:

Cu_2S (Cu, 2 lbs., S, 0.5 lb.)	2.5 lbs.
ZnS (Zn. 4 lbs., S, 2 lbs.)	6.0 lbs.
FeS (Fe, 5.6 lbs., S, 3.2 lbs.)	8.8 lbs.
Total matte	17.3 lbs.

The iron sulphide in this case is computed as follows. After taking out the copper and zinc sulphides, there remains 3.2 sulphur, which is calculated to its required iron on the formula FeS.

We now subtract the 5.6 iron from the total iron:

$9.1 - 5.6 = 3.5$ = iron to be computed into the slag.

This 3.5 iron is equivalent to 4.5 FeO, viz:

$$56 : 72 = 3.5 : 4.5 \text{ (Fe : FeO = Fe : FeO)}$$

Neglect the ash of the fuel in this case.

Statement for Slag Computation.— Let $100x$ = iron flux, $100y$ = limestone. We now get the usual expressions for silica, iron, and lime. We assume that the alumina and such other bases as may find their way into the slag are included in the 10 per cent. allowance, as already explained.

The conditions to be equated are:

$$SiO_2 : FeO = 30 : 40, \text{ or } 4 \times SiO_2 = 3 \times FeO \quad (1)$$
$$FeO = 2CaO \quad (2)$$

Tabulate all expressions for the constituents, and sum up:

	Silica.	Iron oxide.	Lime.
Ore	55.0	4.5	...
Iron flux	$12x$	$76.5x$	...
Limestone	$10y$	...	$50y$
Totals	$55 + 12x + 10y$	$4.5 + 76.5x$	$50y$

Equating according to conditions (1) and (2) as given above we have:

$$4(55 + 12x + 10y) = 3(4.5 + 76.5x) \quad (1)$$
$$4.5 + 76.5x = 2 \times 50y \quad (2)$$

These equations give us:

$$x = 1.356, \text{ or, } 100x = 135.6 \textit{ lbs. for iron flux}$$
$$y = 1.082, \text{ or, } 100y = 108.2 \textit{ lbs. for limestone}$$

Check:

$$SiO_2 = 55 + 12x + 10y = 55 + 16.27 + 10.82 = 82.1 \text{ lbs. } SiO_2$$
$$FeO = 4.5 + 76.5x = 4.5 + 103.73 = 108.2 \text{ lbs. FeO}$$
$$CaO = 50y = 54.1 \text{ lbs. CaO}$$

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We now find that:

$$82.1 : 108.2 : 54.1 = 30 : 40 : 20 \text{ (or } 3 : 4 : 2)$$

The conditions are therefore satisfied by the values found.

In practice it would be the aim to secure as the "iron-flux," an ore carrying "values." If an oxide ore could not be found, then a pyritous ore, roasted to ferric oxide, might be the available material.

The case is quite as good for an exercise as one of greater "probability."

(4) **Mixture of Ores for "Self-Fluxing."**—Three ores, supposed to be each obtainable in suitable quantities, are to be mixed so as to afford a slag of the following composition:

Silica	40 per cent.
Iron oxide	30 per cent.
All other bases	30 per cent.

Analyses of the three are as below (per cent.):

	I.	II.	III.
Silica	50	10	20
Iron oxide	20	70	10
All other bases	10	5	40

None of these analyses give "summation" to 100. The deficits are supposed to include all elements which are reduced, volatilized, or enter the matte.

Assume 100 lbs. of "I" as basis for the mixture. Find weights of Nos. II and III required for the formation of the stated slag.

Let $100x$ = pounds of No. II. Let $100y$ = pounds of No. III.

Collect as usual the expressions for silica, iron-oxide and "bases."

	SiO_2.	FeO.	Bases.
I	50	20	10
II	$10x$	$70x$	$5x$
III	$20y$	$10y$	$40y$
	$50+10x+20y$	$20+70x+10y$	$10+5x+40y$

We select as conditions to be equated, first, that silica is to iron-oxide as 40 is to 30 (or as 4 is to 3); second, that the iron-oxide equals all the other "bases" in weight.

$$3\,(50 + 10x + 20y) = 4\,(20 + 70x + 10y) \quad (1)$$

$$20 + 70x + 10y = 10 + 5x + 40y \quad (2)$$

Hence:

$x = 0.371$ or $100x = 37.1$ = lbs. of No. II in the mix.

$y = 1.137$ or $100y = 113.7$ = lbs. of No. III in the mix.

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The mixture, then, will be:

No. I	100 lbs.
No. II	37.1 lbs.
No. III	113.7 lbs.
Total weight of charge	250.8 lbs.

Proof:

	SiO_2.	FeO.	Bases.
I	50.0	20.0	10.0
II	3.7	25.97	1.85
III	22.74	11.37	45.48
Totals	76.44	57.34	57.33

These totals are in the ratio 40 : 30 : 30, so that the proof is perfect.

(5) The following, with an *unnecessary condition of solution* annexed, is given to accustom the student to reasoning on the whole subject of ratios and excess. Afterward the same data are treated by the equation method, by way of contrast.

Example.—The ore contains 40 per cent. SiO_2, and no slagging bases.

Take in this case *1,000 lbs.* ore instead of the usual 100 lbs.

Iron-ore flux..... SiO_2 = 8 per cent.; FeO = 82 per cent.
Limestone..... SiO_2 = 5 per cent.; CaO = 53 per cent.

Required slag $(FeO)_2,SiO_2 + (CaO)_2,SiO_2$. That is, a singulo, with iron oxide and lime in equal *chemical* ratio.

The requirement of solution is, that two numbers showing the *relative* weights of these two fluxes must be first obtained, *without working out the analysis from the formula.*

The absolute weights are then to be deduced, using the SiO_2 of the main ore in doing so. The final weights serve of course for the deduction of the analysis, it being part of the condition that it is *only in this way that the analysis may be figured.*

Solution (1) Excess FeO in the iron flux.

$$60 : 144 = (5 : 12) = 8\,SiO_2 : 19.2\,FeO$$

Next, 82 − 19.2 = 62.8, which is excess of FeO in the iron flux in *terms of its own percentages.*

(2) Excess CaO in limestone.

$$60 : 112 = (15 : 28) = SiO_2, (5) : 2CaO, (9.33)$$

Then, 53 − 9.33 = 43.67 CaO excess in *terms of limestone percentage.*

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(3) Find SiO_2 required by excess iron oxide, and SiO_2 required by excess lime, each in terms of percentages of respective fluxes.

(*a*) $144 : 60 = (12 : 5) = 2FeO, (62.8) : SiO_2, (26.17)$

which is SiO_2 required for the iron flux in terms of its own percentages.

(*b*) $112 : 60 = (28 : 15) = 2CaO, (43.67) : SiO_2, (23.39)$

which is SiO_2 required by limestone in terms of limestone percentages.

These two amounts of SiO_2, at present purely abstract, have to come from the main ore.

Call weight of iron flux $100x$, weight of limestone $100y$.

Evidently, since there is neither iron nor lime in the main ore:

$$82x : 53y = 72 : 56 = 9 : 7$$

Whence:

$$574x = 477y, \text{ otherwise } x : y = 477 : 574$$

These numbers, then, are the *relative* weights of iron flux and limestone. If they be respectively multiplied by their percentages of SiO_2 deficit we shall have two numbers, still abstract, denoting the *relative amounts of SiO_2* to be taken from the main ore by the two fluxes.

Making these multiplications, we have for:

Iron flux..... $477 \times 26.167 = 12482+$

and for:

Limestone..... $574 \times 23.391 = 13426+$

Sum of products..... $= 25908$

It is evident that if we divide the total silica of the ore, 400 lbs., into 25,908 parts, the iron flux will take 12,482 and the limestone 13,426 of them. However, to bring decimals of pounds into their proper position we call the two numbers 124.82 and 134.26. Divide the 400 lbs. by the sum of products, which has now become 259.08; we get 1.5439 lbs. This is "*one part*" of silica. We now multiply it by the relative "demands" of the two fluxes.

$1.5439 \times 124.82 =$ for FeO..... 192.709598 lbs.
$1.5439 \times 134.26 =$ for CaO..... 207.284014 lbs.

Total..... 399.99+ or 400 lbs.

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Adjudicate back from these *actual* weights, as follows:

For CaO . 60 : 112 = (15 : 28) = 207.3 : 386.96 CaO
For FeO . 60 : 144 = (5 : 12) = 192.7 : 462.48 FeO

Divide the first of these results by .4367 we get limestone *886.9 lbs.* Divide second result by .628 we get iron-ore flux *736.4 lbs.*

(These divisors are the original basic excesses already obtained.)

Proof will be worked out after the second solution is given by equation method. To this we now proceed.

Solution (by equations) of the last problem.

Same data and same requirements as above.

Iron-ore flux = $100x$. Limestone = $100y$.

Take ratios directly from formula, without reducing same to 100 per cent. basis. We get:

$2SiO_2$	120
2FeO	144
2CaO	112

These numbers reduced to their lowest terms are as 15 : 18 : 14. Take as indicated by the method, the representations of the elements of the slag, and equate according to these ratios:

$$(400 + 8x + 5y) : 82x = 15 : 18 = 5 : 6 \quad (1)$$

$$82x : 53y = 18 : 14 = 9 : 7 \quad (2)$$

$100x = 736.$ $100y = 886.$

The case is wholly exceptional, as it would be rare indeed to find an ore with nothing but silica entering the slag.

Proof.—We take the original figures from solution first given:

Actual charge. SiO_2 from 1,000 lbs. ore	400.00 lbs.
SiO_2 5 per cent. from 886.96 lbs. limestone	44.345 lbs.
SiO_2 8 per cent. from 736.4 lbs. iron flux	58.912 lbs.
Total silica in actual charge	503.257 lbs.

Compare this with SiO_2 deduced by adjudication with bases:

(CaO) 112 : 60 = 28 : 15 = 470.057 :	251.81 lbs.
(FeO) 144 : 60 = 12 : 5 = 603.848 :	251.60 lbs.
Total calculated silica	503.41 lbs.

Dropped decimals account for certain trivial discrepancies here and in the checking of the answers by the two methods.

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As to the relation of FeO to CaO it should be as 72 : 56 = 9 : 7.

CaO in charge = 53 per cent. of 886.9 = ... 470.057 lbs.
FeO in charge = 82 per cent. of 736.4 = ... 603.848 lbs.
603.8 : 470 = 72 : 56 = 9 : 7. Q.E.D.

In spite of the fanciful restrictions laid upon the first solution, we recommend the student to master it. A hundred formal rules for the solutions of a hundred cases are not worth one fundamental principle. Considerations very similar to those used in this "fancy" case are not uncommonly required. Ratios and stoichiometric relations are easy, but it is only after "handling" them in every style that the student is prepared to meet any possible problem—and to meet it easily and correctly.

(6) The following somewhat elaborate example is a good case for the equation method. As will be seen it results in too large an addition of fluxing material, a fact that has nothing to do with the correctness of the operations in a mathematical sense.

We here apply all the "simplifications" exemplified, adding also ash of the fuel. The example, with its proof by assembly of all constituents, forms a general "type" case for similar problems.

Analyses of material, ore, fuel and fluxes. *The ash of the coke constitutes 12 per cent. of same.*

Ore charge, 1000 lbs.; coke (additional to ore), 150 lbs. Weights of iron ore flux and limestone to be found from conditions.*

	Ore.	Ash of coke.	Iron ore flux.	Limestone.
SiO_2	56.00	70.00	6.00	4.00
Fe	22.00	(FeO)20.00	(FeO)81.00†	....
Cu	5.00	....	....	....
Mn	2.00	....	....	....
As	.40	....	....	....
S	4.00	....	....	....
CaO	3.00	10.00	....	48.16
MgO	....	....	....	4.76
Al_2O_3	....	....	4.00	....
Deficit (O, etc.)	7.60	....	....	....
	100.00	100.00	100.00	

* The usual 100 lbs. for basis of calculation is not adopted in this particular case. There is no especial reason for departing from our usage, except to show that in doing so we are making a little trouble for ourselves, also slightly increasing liability to error. For, in taking weights of constituents from ore analysis, we are apt to forget to multiply by ten.

† The Fe_2O_3 equals 90 per cent.

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As the charge is one thousand lbs., the weight in pounds of any constituent is the percentage multiplied by ten. It will be convenient to calculate in lbs., so we start by putting the analysis of the coke ash in that shape. The coke being fifteen per cent. of the ore charge, weight of the ash is 18 lbs., viz:

FeO	3.60 lbs.
SiO_2	12.60 lbs.
CaO	1.80 lbs.
	18 lbs.

This is presently to be added into the ore weights.

The Al_2O_3 of the iron flux is now put into the lime column, factor 1.65. Thus, $4 \times 1.65 = 6.6$ "conventional" lime coming from iron flux.

The MgO of the limestone is similarly treated. Thus, $4.76 \times 1.4 = 6.66$, and $48.16 + 6.66 = 54.82$, which is to be taken as the CaO figure from the limestone.

Next we put the ore into shape, taking out matte and speiss.

As these operations have been fully illustrated we here give results, to be verified by the student.

Calculation for Cu_2S gives	62.5 lbs.
For FeS	51.56 lbs.
For Fe_5As	18.93 lbs.
	132.99 lbs.

Or say 133 lbs. matte and speiss per charge. (This on the assumption that neither sulphur nor arsenic will be volatilized.)

Finally we put manganese and iron into the shape of their protoxides, and then add these together, the sum becoming the FeO of the ore. Again we give results only—*i.e.*, FeO, 232.71 lbs.; MnO, 25.82 lbs. To this is added the FeO from the coke ash, 3.60 lbs.

To the SiO_2 of the ore add 12.60 from coke ash. To its CaO add 1.8 from coke ash. The coke ash is now disposed of, and, like the matte and speiss, no longer enters into the calculation.

The revised analyses, omitting the elements just spoken of, now read:

	Ore, lbs.	Iron flux, per cent.	Limestone, per cent.
SiO_2	572.6	6.00	4.00
(Fe, Mn,) O	262.13	81.00	....
CaO	31.80	6.60	54.82

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Conditions.—Mix for a singulo silicate slag, whose iron oxide shall be twice the lime (chemically), that is for formula:

$$(FeO)_4, (SiO_2)_3 + (CaO)_2, SiO_2$$

This formula reduces to an analysis showing SiO_2, 31+ per cent; FeO, 50+ per cent.; CaO, 19+ per cent.

To simplify the calculation, we take one per cent. from silica and add one to lime, making the ratios:

$$SiO_2 : FeO : CaO$$
$$3 : 5 : 2$$

The silica looks rather too low for safe running. But we have three facts that make for greater tractibility than the percentage might suggest. The first is that the weights of bases are *less than shown by the revised analyses*, since Al_2O_3 and MgO have been multiplied "to make lime of them." The second is that large iron percentage makes for fluidity. The third is that the slag is poly-basic (Fe, Mn, Al_2O_3, CaO, MgO); this also favors fusion.

The statement with the usual proviso: "iron flux = $100x$, and limestone = $100y$," is made as already exemplified.

$$2(572.6 + 6x + 4y) = 3(31.8 + 6.6x + 54.82y) \quad (1)$$
$$2(262.13 + 81x) = 5(31.8 + 6.6x + 54.82y) \quad (2)$$

(1) reads: "Silica is to lime as 3 : 2."
(2) reads: "Iron oxide is to lime as 5 : 2."

The solution gives: $x = 10.325$ and $y = 6.195$, or
Iron ore flux 1032.5 lbs. and limestone 619.5 lbs.

Proof.—Assemble all expressions for the three constituents. Multiply the literal expressions by values of x or y, add and compare according to the condition

"$SiO_2 : FeO : CaO = 3 : 5 : 2$."

$SiO_2 = 572.6 + 61.95 + 24.78 = 659.33$ lbs.
$FeO = 262.13 + 836.325 = 1098.455$ lbs.
$CaO = 31.80 + 68.45 + 339.610 = 439.555$ lbs.

Multiply SiO_2 by 2 and CaO by 3.

$$659.33 \times 2 = 1318.66 \qquad 439.555 \times 3 = 1318.66$$

Multiply SiO_2 by 5 and FeO by 3.

$$659.33 \times 5 = 3296.65 \qquad 1098.455 \times 3 = 3295.36$$

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INDETERMINATE CASES.

An indeterminate case is one in which several mixtures may bring about the required condition.

Generally, a problem to which there are several answers, sometimes an infinite number of answers, may be called indeterminate.

Algebraically, an equation containing two unknown quantities (x and y), with no other condition or equation to assist the solution, is called an "indeterminate" equation. The same term may be applied to two equations involving three unknown quantities, etc.

There are cases in which, although but one answer is possible (at least but one rational answer), the statement is nevertheless indeterminate in form. These are not considered. They are wholly exceptional in metallurgical practice. Discussion of a single ordinary case, in which several mixes alike meet the general requirement, will be sufficient. In accordance with our precedents this is made extremely simple.

Example.—We have three ores and a limestone, whose analyses, as to slagging constituents, are as follows:

	SiO_2.	Bases.	Lime.
Ore No. 1	50	30	.. per cent.
Ore No. 2	40	20	.. per cent.
Ore No. 3	30	10	.. per cent.
Limestone	10	..	50 per cent.

The *ore* charge is to be 1,000 lbs. Requirement for the slag as below, viz:

Silica	50 per cent.
Bases from the ore mixture	25 per cent.
Lime from the limestone	25 per cent.
	100 per cent.

There are several ways of taking up the solution; we adopt the equation method as the most general.

Let $100x$, $100y$, $100z$, and $100v$ represent respectively the weights of ores Nos. 1, 2, 3, and of the limestone. The last

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($100v$) is inserted to give generality to the discussion, as its value can be deduced without any formal calculation.

The constituents are now represented by the same figures as their respective percentages, all with the unknown quantities annexed, viz:

	SiO_2.	Bases.	Lime (CaO).
I	$50x$	$30x$	...
II	$40y$	$20y$	...
III	$30z$	$10z$	...
Limestone	$10v$	...	$50v$

There are three equations on the conditions:

$$100x + 100y + 100z = 1000 \text{ or } x + y + z = 10 \quad (1)$$
$$30x + 20y + 10z = 50v \quad (2)$$
$$50x + 40y + 30z + 10v = 30x + 20y + 10z + 50v \quad (3)$$

No. 3 reduces to $x + y + z = 2v$

Hence by (1) $2v = 10$ and $v = 5$. Limestone ($100v$) = 500 lbs.

The limestone therefore is constant for all possible mixes under the conditions. This, as already mentioned, might have been deduced without the formality of an equation.

The two equations remaining reduce to:

$$(a)\ x = 5 + z \text{ and } (b)\ y = 5 - 2z$$

Two equations with three unknown quantities: "Indeterminate."

Discussion of the maximum and minimum values of each of the unknowns is, however, exceedingly simple. Take z first, as it occurs in both equations:

(a) shows that 0 is a possible value of z (minimum).

(b) shows that with $y = 0$, z has its maximum value of 2.5.

Substituting in (a) we find x has a maximum value of 7.5, minimum of 5.

Substituting in (b) y has a maximum value of 5, minimum of 0.

Or, writing the values multiplied by 100, which express the weights of ore:

	Maximum.	Minimum.
Ore No. 1, lbs	750	500
Ore No. 2, lbs	500	0
Ore No. 3, lbs	250	0

(Limestone, always 500 lbs., for any mixture.)

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We see that ore No. 1 must always be used, and with it some portion of No. 2 or No. 3, or both, according to weight of No. 1 taken. Any violation of the equations violates also the slag condition, as may be easily shown.

Take maximum of No. 1, No. 2 goes to its minimum (zero); No. 3 to maximum, 250.

Take minimum of No. 1, No. 3 goes to its minimum (zero); No. 2 to maximum, 500.

In all other cases, viz: No. 1 somewhere between maximum and minimum, all three of the ores enter the mix. Assume for x any value between limits, substitution in equations (a) and (b) gives values to y and z.

Examples under each case:

(a) Ore No. 1, take maximum weight of same. Calculate bases and silica.

No. 1, 750 lbs.; No. 2, 0; No. 3, 250; total, 1000 lbs.

	SiO_2.	"Bases."	CaO.
From I	375	225	... lbs.
From II	0	0	... lbs.
From III	75	25	... lbs.
Limestone	50	...	250 lbs.
Total	500	250	250 lbs.

(b) Ore No. 1, take minimum weight.

No. 1, 500 lbs.; No. 2, 500 lbs.; No. 3, zero.

	SiO_2.	"Bases."	CaO.
From I	250	150	... lbs.
From II	200	100	... lbs.
From III	0	0	... lbs.
From limestone	50	...	250 lbs.
Total	500	250	250 lbs.

(c) Ore No. 1, take weight intermediate between maximum and minimum.

No. 1, 700 lbs.; No. 2, 100 lbs.; No. 3, 200 lbs.

	SiO_2.	"Bases."	CaO.
From No. 1	350	210	... lbs.
From No. 2	40	20	... lbs.
From No. 3	60	20	... lbs.
From limestone	50	...	250 lbs.
Total	500	250	250 lbs.

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Conditions satisfied in every case—*i.e.*, silica always equal to bases, and CaO always equal to bases from the ores. The problem is thus reduced to finding maximum or minimum which can be used of the three ores. It has found application in increasing or decreasing use of a certain ore, according to supply or cost.

Novices in algebraic statement often attempt to get as many equations as there are unknown quantities, in an indeterminate case. For instance, another equation which in reduced form would read $5x + 4y + 3z = 45$ could be taken to represent the condition that $SiO_2 = 2 \times CaO$. But this is already implied in the equations above, so that in eliminating x we merely regain the old form $y = 5 - 2z$.

Pyritic Smelting.

The calculations for slag in pyritic smelting are necessarily less definite than for other forms. This arises from the uncertainties of oxidation, as it is not possible to predict exactly what proportion of FeS_2 will be oxidized—*i.e.*, how much will go into matte and how much into slag.

In the absence of experimental data, the safe plan is to adopt a mixture that can hardly give a slag either very high or very low in silica. The conditions that modify oxidation are many, some of them under control, some to be learned only by experiment at the particular plant in question, with its limitations as to ores and fluxes.

Thus, the shape of the furnace; the relation of blast to fuel and charge; the pressure of the air, and especially its temperature; the proportion of finely divided sulphides to larger masses of quartz; the fusibility of the probable slag; all these and other considerations make the computation of the charge for pyritic or semi-pyritic smelting a very uncertain matter as compared with the perfectly definite estimates for mixtures already oxidized. This applies with especial force to the practice at a plant as yet untried. So far as relates to slag calculation the operation is a roasting and simultaneous fusion of ore, with the great disadvantage that there is no possible way to ascertain the composition of the roasted ore—*i.e.*, of the materials just as they separate into matte and slag.

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Thus there are less of physical and arithmetical data than in any other case. So far as the computations go, however, they are the same as for cases already taken up. One example must suffice. Its data are close to an actual instance, but have been simplified by taking nearest whole numbers.

Example.—The ore analyzes:

SiO_2	40.00 per cent.
FeS_2	45.00 per cent.
CuS	9.00 per cent.
Bases	6.00 per cent.
Total	100.00 per cent.

Assume that two-thirds of the iron will go into the slag and one-third into the matte. The weight of the copper is assumed as six per cent., that being a close approximation, then the analysis of the ore by elements is:

SiO_2	40.00 per cent.
Fe	21.00 per cent.
Cu	6.00 per cent.
S	27.00 per cent.
Bases	6.00 per cent.
Total	100.00 per cent.

Under the assumption above, we have for the slag 40 lbs. SiO_2, 18 lbs. FeO, and 6 lbs. of other bases. Total, 64 lbs. ($FeS_2 \times .6 = FeO$.)

The matte should contain: FeS, 11 lbs.; Cu_2S, 7.5 lbs. ($Cu_2 : S = 4 : 1$).

Total matte 18.5 lbs. Its analysis:

Cu	32.43 per cent.
Fe	37.83 per cent.
S	29.73 per cent.
	99.99 per cent.

The slag would analyze no less than *65 per cent. of SiO_2.*

This being far too silicious to risk, especially upon an uncertain basis as indicated above, it would be necessary to add limestone. Suppose we have limestone of the composition SiO_2 10 per cent. and CaO 50 per cent. We calculate for *50 per cent. silica in the slag.* In the case here "set up," the equation and calculations are very simple.

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Make the usual figures—*i.e.*, 100 lbs. ore, $100x$ lbs. limestone.

$$40 + 10x = 24 + 50x$$

$100x = 40$ lbs. Limestone required, 40 lbs.

Proof:

SiO_2 in 100 lbs. ore	40 lbs.	44 lbs.
SiO_2 in 40 lbs. limestone	4 lbs.	
FeO in 100 lbs. ore	18 lbs.	44 lbs.
Bases 100 lbs. ore	6 lbs.	
CaO in 40 lbs. limestone	20 lbs.	

Silica equals 50 per cent. as required.

Analysis of this slag:

SiO_2	50.00 per cent.
FeO	20.45 per cent.
CaO	22.73 per cent.
Other bases	6.82 per cent.
Total	100.00 per cent.

Some Well-Known "Formulæ."

The following are analyses of six formulated slags. They are all of the type of two base slags, here assumed as iron oxide and lime.

(1) Singulo with iron oxide and lime in equal chemical ratio. $(FeO)_2, SiO_2 + (CaO)_2, SiO_2$. Simplified ratios at right.

	Per cent.	Per cent.	Ratios.
SiO_2	31.91	32	15
FeO	38.30	38	18
CaO	29.79	30	14
	100.00	100.00	

The ratios 15 : 18 : 14 are exact, and easy to use in computation.

(2) Sesqui-silicate—same iron-lime ratio.

$$4FeO, 3SiO_2 + 4CaO, 3SiO_2$$

	Per cent.	Per cent.	Ratios.
SiO_2	41.28	41	5
FeO	33.03	33	4
CaO	25.69	26	3
	100.00	100.00	

Ratio 5 : 4 : 3 is sufficiently close for figuring.

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(3) Bi-silicate, iron oxide and lime in equal ratio.

$FeO, SiO_2 + CaO, SiO_2$

	Per cent.	Ratios.
SiO_2	48.39	15
FeO	29.03	9
CaO	22.58	7
	100.00	

Ratio 15 : 9 : 7 is exact, being same as 120 : 72 : 56 or $2SiO_2$: FeO : CaO.

(4) Singulo, iron oxide twice lime, chemical ratio.

$4FeO, 2SiO_2 + 2CaO, SiO_2$

	Per cent.	Ratios.
SiO_2	31.03	3
FeO	49.65	5
CaO	19.31	2
	100.00	

(5) Sesqui-silicate, iron oxide twice lime.

$8FeO, 6SiO_2 + 4CaO, 3SiO_2$

	Per cent.	Ratios.
SiO_2	40.31	15
FeO	42.98	16
CaO	16.71	6
	100.00	

(6) Bisilicate, iron oxide twice lime.

$2(FeO, SiO_2) + CaO, SiO_2$

	Per cent.	Ratios.
SiO_2	47.37	6
FeO	37.90	5
CaO	14.73	2
	100.00	

Variations on these formulæ could be given almost ad infinitum. The above are six well known forms. The suggestions on the right of simpler ratios are meant to provide small numbers for multipliers in the statement equations, or in any other method of treatment of the computations. Their variation from the ratio of the precise analysis is not great in any case, and in some the ratios are identical. We repeat, that nothing that diminishes the chances of error is too trivial for attention.

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Something has already been said as to the difference between assuming a fixed weight for ore alone, and calculating for the weight of the entire charge, as a fixed quantity.

Suppose the latter method be chosen, and we are to work it by equations. The fact that the entire weight is fixed in advance furnishes us with a third equation, and we shall have three simultaneous equations instead of two, to solve. We illustrate by simple data in the following:

Example.—Three ores analyze as follows:

	I.	II.	III.
Silica	10	40	.. per cent.
Iron oxide	20	..	20 per cent.
Other bases	..	10	15 per cent.

These are to be smelted without addition of other material. The charge is to be one thousand pounds.

The slag is to contain SiO_2, 50 per cent.; FeO, 30 per cent.; other bases 20 per cent.

Equations are as follows, taking $100x$, $100y$, and $100z$ as the weights.

$$100x + 100y + 100z = 1000 \text{ (or, } x + y + z = 10)$$
$$10x + 40y = 20x + 10y + 35z$$
$$2(20x + 20z) = 3(10y + 15z)$$

These give following weights for the mix:

No. I, 338 lbs.; No. II, 408.5 lbs.; No. III, 253.5 lbs. Total 1000 lbs.

Now assume one hundred lbs. for No. I., and $100x$ and $100y$ as others.

$$10 + 40x = 20 + 10x + 35y$$
$$2(20 + 20y) = 3(10x + 15y)$$

Weights: No. I, 100 lbs.; No. II, 120.83 lbs.; No. III, 75 lbs. Sum of weights is 295.83.

$$\frac{1000}{295.83} = 3.38+$$

Factor, 3.38. Multiply each weight as just found by this; we get the same results as before.

Usually it is easier to assume the fixed weight of one ore than to solve for the mix. We have also the less liability of error. In substituting values in the solution of simultaneous equations, a trivial error in value of one unknown may make quite a serious

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one in the value of another. As a rule, two simultaneous equations are sufficient, and it is better to limit them to this number if possible.

A few examples are annexed, with neither statements nor solutions. These are inserted as working examples to check on, answers being given.

Example:

	Ore.	Iron flux.	Limestone.
SiO_2	40	8	.. per cent.
FeO	10	80	.. per cent.
CaO	..	..	50 per cent.

Slag required $(FeO)_2\ SiO_2 + (CaO)_2\ SiO_2$, *i.e.*, singulo with iron oxide and lime in equal chemical ratio. Take 100 lbs. of ore.

(This slag analyzes to nearest per cents as follows: SiO_2, 32 per cent.; FeO, 38 per cent.; CaO, 30 per cent.; these may be taken as data for solution.)

Answers:—Ore, 100 lbs. Iron flux, 59.2 lbs. Limestone, 90.7 lbs.

Example.—Calcined ore, no fluxes. Take out the matte and calculate the slag, making the following suppositions as to combinations and losses, viz: All of the copper goes into matte. Three-fourths of the lead and one-half of the zinc also go into matte, taking precedence of the iron. All of the remaining sulphur combines with iron. (FeS in matte.)

One-half of the zinc goes into slag, and one-fourth of the lead. All of iron not put into matte goes into slag.

Take 100 lbs. of this ore, find weight and analysis of matte and slag. No allowances for losses of volatile material.

Analysis of the calcined ore:

SiO_2	27.3	per cent.
Cu	11.9	per cent.
Fe	37.5	per cent.
Zn	2.0	per cent.
Pb	1.0	per cent.
CaO	4.0	per cent.
S	7.0	per cent.
O, etc	9.3	per cent.
	100.00	per cent.

Answer: Weight of matte per 100 lbs. ore taken = 26.65 lbs.

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Analysis of matte:

Cu_2S	55.91 per cent.
FeS	35.27 per cent.
ZnS	5.63 per cent.
PbS	3.19 per cent.
	100.00 per cent.

Weight of slag per 100 lbs. of ore taken = 73.35 lbs.
Analysis of slag:

SiO_2	37.24 per cent.
FeO	55.23 per cent.
CaO	5.45 per cent.
ZnO	1.71 per cent.
PbO	0.37 per cent.
	100.00 per cent.

Example.—Take a partly roasted product whose analysis follows:

SiO_2	62.00 per cent.
Al_2O_3	10.00 per cent.
Fe	14.42 per cent.
Cu	6.40 per cent.
S	4.51 per cent.

Assume the deficit of this analysis (2.67) as oxygen.

Take out the matte (Cu_2S + FeS), then, since the remaining constituents are highly silicious, fuse with a limestone having composition SiO_2 = 10 per cent. and CaO = 50 per cent., charging for *bisilicate slag*, no special ratio being required as between bases.

Find what the analysis of this bisilicate slag should be.

Answer:

SiO_2	56.38 per cent.
Al_2O_3	8.07 per cent.
FeO	9.68 per cent.
CaO	25.87 per cent.
	100.00 per cent.

Example.—Use the same data as in the last example. Instead of charging for a bisilicate slag, charge for a singulo of this formula:

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$4FeO + 2CaO + 3SiO_2$, in which FeO and CaO are in true chemical ratio as shown by formula.

Treat the Al_2O_3, *however, as "outside" of this formula*, that is, take out from the ore the singulo silicate of Al_2O_3 before calculating the other fluxes. The slag, then, is to consist of a singulo silicate of Al_2O_3, *plus* the above formulated silicate of iron and lime.

For this charge, in addition to the limestone given, use an iron ore flux whose analysis gives SiO_2 = 10 per cent. and FeO = 81 per cent.

Take 100 lbs. of ore, $100x$ and $100y$ lbs. of iron flux and limestone.

Give weights of the latter to be added. Give analysis of the complete slag, *i.e.*, the constituents including the Al_2O_3.

Answers: Weight of iron flux = 135.8 lbs.; weight of limestone = 94.665 lbs.

Analysis of slag:

SiO_2	32.13 per cent.
Al_2O_3	3.82 per cent.
FeO	46.15 per cent.
CaO	17.90 per cent.
	100.00 per cent.

Example.—A partly roasted ore analyzes as follows:

SiO_2	26.00 per cent.
Cu	9.00 per cent.
Fe	41.35 per cent.
Zn	2.00 per cent.
Pb	4.00 per cent.
S	8.00 per cent.
O (deficit)	9.65 per cent.
	100.00 per cent.

Take out matte, assigning to it all the copper, half of the zinc, three-fourths of the lead, and as much iron as the "residual" sulphur permits on FeS formula. Consider the lead not entering the matte as "lost," making no allowance for it in the slag computation.

Find analysis of the matte, also the remaining constituents of slag.

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Answer.—Analysis of the matte:

Cu.....	9	+ S 2.27 =	11.27 =	38.39 per cent.	Cu_2S
Fe.....	8.35	+ S 4.77 =	13.12 =	44.70 per cent.	FeS
Zn.....	1	+ S 0.50 =	1.50 =	5.11 per cent.	ZnS
Pb.....	3	+ S 0.46 =	3.46 =	11.80 per cent.	PbS
				100.00 per cent.	

Analysis of the slag:

SiO_2.....	37.33 per cent.
FeO.....	60.87 per cent.
ZnO.....	1.79 per cent.
	99.99 per cent.

This slag, however, formed simply from residual elements after matte has fallen, being considered too heavy, lime addition is desired. Limestone to be used has following analysis: SiO_2 = 7 per cent.; CaO = 52 per cent.

Condition.—Enough of this limestone shall be added to reduce the silica in the slag to 32 per cent.

Answer.—Weight of the limestone = 31.24 lbs.

Analysis of resulting slag:

SiO_2.....	32.00 per cent.
FeO.....	48.14 per cent.
CaO.....	18.43 per cent.
ZnO.....	1.42 per cent.
	99.99 per cent.

Example.—Resume the last example at the point where we have to compute the limestone necessary to add for production of 32 per cent. silica in the slag.

Instead of calculating this by either excess or equation method, we may use the "mixing" rule. But in doing so we must remember that 41 per cent. of the limestone is volatile matter, and 59 per cent. is "fixed," so the addition for this method must be treated as the non-volatile portion only. We may mix the "potential" slag we have already, with its 37.33 per cent. silica, *with the non-volatile portion of the limestone,* which, as a simple calculation will show, gives 11.86 per cent. silica ($7 \times 100 \div 59 = 11.86$).

The application of the "mixing" rule now becomes:

37.33 less 32 = 5.33. And 32 less 11.86 = 20.14.

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Weight of the slag, which of course had to be found before getting its analysis, is 69.65 pounds. We have then:

$$20.14 : 5.33 = 69.65 : 18.43$$

Finally, $$\frac{18.43}{.59} = 31.24$$

or exactly the same result as calculated in the former example, as required weight of limestone to be added.

Burdening of the Iron Furnace.

The frequent change of the fuel ratio in the iron blast furnace has naturally brought about the custom of separate estimates of limestone charge for fuel and for ore. Thus, by allotting a certain weight of "stone" for each 100 lbs. of ore and for each 100 lbs. of fuel, the necessity of recomputing at every change of the fuel ratio is avoided.

It is the practice of many iron furnaces to consider alumina as an acid constituent of the slag. The alumina and the silica are simply added together, and called the "acid;" the same is done with all the bases, which are then computed "en masse" against the "acid."

The minimum figure adopted for "acid" is forty per cent.; the maximum is 50 per cent. To put it otherwise, the ratio of acid : base = 40 : 60 or in simplified ratio 2 to 3, shows the least proportion of acid, while equal weight of acid and base shows the highest allowable "acid." Usually a figure near equality is selected, especially if sulphur is present, as in that case some addition of limestone is common, in excess of the weight figured for slag.

These usages, far from introducing any new factor into the problem, reduce it to its most elementary form.

The data in the following example are taken from Robert Forsythe's work, "The Blast Furnace and the Manufacture of Pig Iron." (David Williams & Co., New York, 1908.) We drop from the tabulated analyses the sulphur, phosphorus, iron, and carbon, and confine computation to the slag-forming elements.

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The problem is set forth on pages 168–171 of the above work.

	Fuel.	Ore.	Limestone.
SiO_2	5.30	7.49	0.64
Al_2O_3	3.00	0.81	0.32
CaO	1.00	0.15	54.20
MgO	0.70	0.12	0.35
Mn	....	0.45	....

As in the text we require a slag:

$$\text{acid} : \text{base} = 10 : 11$$

In order that our data may wholly coincide, we again adopt the text in subtracting 1.80 from the "acid" for silica reduced to silicon. We also assume that one-third of the manganese goes into the slag as MnO; this gives 0.2 MnO.

To compute "stone" required for the fuel, on basis of 100 lbs., call weight of limestone as usual, $100x$. Then,

$$SiO_2 + Al_2O_3 = 8.30 + 0.96x$$
$$\text{Bases} = 1.70 + 54.55x$$
$$10 : 11 = 8.3 + .96x : 1.7 + 54.55x$$

whence, $100x = 13.89$ = lbs. "stone" required for the fuel.

As to the ore we have (after taking out 1.80 acid):

$$SiO_2 + Al_2O_3 = 6.5 + .96x$$
$$\text{Bases} = .47 + 54.55x$$
$$10 : 11 = 6.5 + .96x : .47 + 54.55x$$

whence, $100x = 12.49$ = "stone" to 100 lbs. of ore.

These results are identical to the one-hundredth of a pound with those obtained in the text. In the latter, however, an addition is now made to the lime for "carrying" sulphur from the ore. This is omitted, as our purpose is confined to showing how readily the equation method can be applied to any case. Observe that in the above computation we take no note of "excess," nor of "flux efficiency," as the basic availability of the "stone" is sometimes called.

On page 250 we remarked that the equation method is relatively easier as the problem becomes more complex. However, the extreme limit of simplicity is reached in the above problem, and it will be found that fewer figures are used by this than by any other method.

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With Al_2O_3 not over five per cent. in the slag, the proportion of MgO is not important. When Al_2O_3 rises to 10 per cent. or over, MgO in excess of twenty per cent. is found to cause viscosity.

It is usual, when sulphur is present, to add limestone *in excess of the slag requirement*, allowing seven *available* CaO to four sulphur (56 : 32). No lime addition, however, will entirely remove sulphur from the pig metal.

In the case above, suppose the fuel contained 0.75 sulphur, the addition of limestone would be 2.45 lbs. for each 100 lbs. fuel. This we leave the student to verify.

In closing this work we again call attention to the fact that we have written mainly for the student.

The method of slag computation by simultaneous equations, first taught by the author in 1883, will be found to be a great labor saver.

The more complex the requirements, the greater will be the *relative* complexity avoided.

The whole of the calculation of "excess" and residual quantities is eliminated.

It is hoped that the publication of this little treatise may prove serviceable to many who have been more or less confused by the irregularities of the methods in vogue.

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